Stratigraphy, Sedimentology and Tectonic setting of the Lampang Group, central north Thailand

by

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This thesis contains no material which has been accepted for the award of any other degree or graduate diploma in any tertiary institution and, to the best of my knowledge and belief, the thesis contains no copy or paraphrase material previously published or written by other person, except when due reference is made in the text of the thesis.

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Abstract

The Lampang Group in central north Thailand is found to have been deposited as two adjacent sub-basins that contain similar lithological sequences which overlap in stratigraphy and age. The Lampang Group proposed here consists of seven formations, in ascending order the Phra That, Pha Kan, Hong Hoi, Doi Long, Pha Daeng, Kang Pla and Wang Chin Formations. The first five formations occur in the Lampang sub-basin in the west whereas the last three formations are in the Phrae sub-basin in the east, and only the Pha Daeng Formation is widespread over both sub-basins. The Lampang sub-basin formed during early Triassic to early late Triassic and contains *Daonella* , *Paratrachyceras* , *Costatoria* and *Claraia* while the Phrae sub-basin formed in late Triassic and contains *Halobia* . This classification contrast sharply with those of Piyasin (1972) and Chonglakmani (1981), who considered lithologic sequences of these two sub-basins as belonging to the same stratigraphic level. The nomenclature of formations in this study also appears to compromise the contradictory names of the previous classifications. Discussion on these is provided.

Both sub-basins contain a similar deepening-upward megasequence, starting with red beds upward to ramp carbonates and submarine fan sediments. The Lampang sub-basin also contains a shallowing-upward megasequence at the top, represented by a lithological change upward to platform carbonates and red beds. Time equivalence among the formations is common, since formations of the red beds and carbonates appear to be formed in relatively narrow areas while the mudstones of submarine fan occurred widely in the basins. The Phra That and Pha Daeng Formations consist mainly of red beds. A detailed sedimentologically study of the Pha Daeng Formation showed that it comprises mainly fining-upward sequences of gravity flow sediments deposited subaqueously under a shallow-water fan delta environment. The Pha Kan, Doi Long and Kang Pla are carbonate formations that were formed mainly in shallow-marine ramp platform, drowned ramp and regressive platform environments. Rapid facies change of the carbonates is common. The Hong Hoi and Wang Chin Formations are mud-dominated and interpreted as having been formed as submarine fan environments with detached sand bodies, that may have been fed by multiple-point sources. Most sandstones display flat bases and no fan lobes.

Volcaniclastic material dominates the majority of the Lampang sandstones. The compositional and chemical variations of the sandstones provide a record of shifting source areas within forearc basins. The source areas changed from active magmatic arcs in the Hong Hoi and Pha Daeng Formations to a combination of active magmatic arcs and recycled orogens during the sedimentation of the Wang Chin Formation. The change in source rocks corresponds well with stratigraphies of the new Lampang Group proposed here, and is interpreted as a result of interaction between the Shan-Thai and westward subducting Indochina terranes. The collision between these two terranes was possibly mild and occurred during late Triassic Period.

ความย่อ

กลุ่มหินลำปาง (Lampang Group) ตั้งขึ้นเมื่อ 20 ปีก่อน สำหรับเป็นตัวแทนของหินอายุ Triassic ในบริเวณภาคเหนือตอนกลางของประเทศไทย กลุ่มหินลำปางพบว่าสะสมตัวอยู่ใน แอ่งสะสมตะกอน 2 แอ่งที่อยู่ติดกันคือ แอ่งย่อยลำปาง และแอ่งย่อยแพร่ซึ่งอยู่ติดมาทางด้านตะวันออก แอ่งย่อยทั้ง 2 แอ่งนี้มีหินที่คล้ายคลึงกัน แต่มีอายุต่างกันมาก แอ่งย่อยลำปางมีอายุจาก Early Triassic ถึง early Late Triassic และประกอบด้วยชั้นหิน 5 หมวด เรียงลำดับจากล่างขึ้นไปบน คือ หินทรายแดง- หินปูน- หินโคลน- หินปูน-หินทรายแดง ลำดับของชั้นหินดังกล่าว แสดงถึง Transgression และติดตามด้วย Regression ของน้ำทะเล สำหรับแอ่งย่อยแพร่ มีอายุในช่วง Late Triassic มีการเรียงลำดับของชั้นหินที่แสดงถึงผลของ Transgression ของน้ำทะเลเพียงอย่างเดียว เรียงลำดับจากล่างขึ้นไปหาบน คือ หินทรายแดง-หินปูน-หินโคลน

การเรียงลำดับของชั้นหิน (stratigraphy) ของแอ่งย่อยลำปางเป็นที่ยอมรับกันโดยทั่วไป ปัญหาอยู่ที่ว่าชั้นหินของแอ่งย่อยแพร่เทียบเคียงได้กับส่วนไหนของแอ่งย่อยลำปาง

จากการสำรวจธรณีวิทยารายละเอียดทางภาคสนามพบว่า หินทรายแดงของแอ่งย่อยแพร่ สามารถเทียบเคียงได้ดี กับหินทรายแดงชุดบนของแอ่งย่อยลำปาง หลักฐานสนับสนุนคือ สามารถ เทียบเคียงได้ในภาคสนาม มีอายุใกล้เคียงกัน และเกิดสะสมตัวในสภาวะแวดล้อมที่เหมือนกัน การค้นพบครั้งนี้คล้ายกับผลการสำรวจของ จงพันธ์ จงลักษมณี และ สวาท เคนวิเศษ (2530) แต่มีความแตกต่าง กับการแบ่งชั้นหินของ สงัด ปิยะศิลป์ (2515) และจงพันธ์ จงลักษมณี (2524) ซึ่งเทียบเคียง หินทรายแดงของแอ่งย่อยแพร่ กับหินทรายแดงของชุดล่างของแอ่งย่อยลำปาง

กลุ่มหินลำปางของรายงานฉบับนี้ประกอบด้วย 7 หมวดหินเรียงลำดับ จากล่างไปหาบนคือ หมวดหินพระธาตุ หมวดหินผาก้าน หมวดหินฮ่องหอย หมวดหินดอยลอง หมวดหินผาแดง หมวดหินก้างปลา และ หมวดหินวังชิ้น ชั้นหินของ 5 หมวดหินล่างสุด พบสะสมตัวในแอ่งย่อยลำปาง ในขณะที่ชั้นหินของ 3 หมวดหินบนสุด ในปัจจุบัน พบสะสมตัวอยู่เฉพาะในแอ่งย่อยแพร่ เนื่องจากชั้นหินของหมวดหินต่างๆ มิได้สะสมตัวแบบขนมชั้น โดยเฉพาะอย่างยิ่งพวกหินปูนซึ่งคงเกิดในโซนแคบและยาว จากผลดังกล่าวทำให้อายุของหมวดหินต่างๆ มีความคาบเกี่ยวกันได้ สาเหตุดังกล่าวอาจเนื่องมาจาก การทรุดตัวของแอ่งที่มีอัตราสูงกว่าการสะสมตัวของตะกอน

กลุ่มหินลำปางส่วนใหญ่ประกอบด้วย หินโคลนทราย ของหมวดหินฮ่องหอยและหมวดหินวังชิ้น ซึ่งเกิดจากการสะสมตัวในสภาวะแวดล้อมแบบ Submarine fans ที่มีขบวนการขนถ่ายตะกอนแบบ multiple-point

sources ชั้นของ หินทราย จะแสดงลักษณะผิวเรียบในส่วนล่าง และบ่อยครั้งที่แสดงลักษณะของการเรียงตัวของเม็ดแร่จากหยาบไปหาละเอียด ส่วนลักษณะที่บ่งถึงความเป็นลำธารหรือท้องน้ำจะไม่ค่อยพบ หมวดหินผาก้าน หมวดหินดอยลอง และหมวดหินก้างปลา จะประกอบด้วยหินปูนที่เกิดในน้ำตื้นเป็นส่วนใหญ่ สภาวะแวดล้อมของการเกิดจะเป็นแบบ ramp platform, drowned ramp และ regressive platform ไม่พบซากปะการังหรือแนวหินโสโครกที่เป็นแบบ Barrier reef แต่มีพวก Patch reef หินทรายแดงของหมวดหินผาแดงเกิดจากการสะสมตัวของตะกอนขุ่นข้นเช่นเดียวกันกับหินทราย ของหมวดหินฮ่องหอยและหมวดหินวังชิ้น แต่ต่างกันตรงที่ว่าของหมวดหินผาแดงเกิดในน้ำตื้น และในสภาวะแวดล้อมที่เรียกว่า Fan delta

กลุ่มหินลำปางสะสมตัวใน forearc basins บน Shan-Thai terrane หินทรายของหมวดหินฮ่องหอยและหมวดหินผาแดง ประกอบด้วยตะกอนของหินภูเขาไฟและหินปูนชายฝั่งเป็นส่วนใหญ่ แสดงถึงการถูกพัดพามาจาก ภูเขาไฟที่กำลังปะทุ (active magmatic arc) หินทรายของหมวดหินวังชิ้นแตกต่างจากของหมวดหินฮ่องหอยตรงที่มีตะกอนของ Quartz มากกว่า หลักฐานจากส่วนประกอบบ่งว่า หินของหมวดหินวังชิ้นถูกพัดพามาทั้งจากภูเขาไฟที่กำลังปะทุและจากแผ่นดินที่กำลังยกตัวการยกตัวของแผ่นดินคงจะเป็นผลเนื่องมาจากการชนกันระหว่าง Shan-Thai terrane กับ Indochina terrane ซึ่งมุดตัวไปทางตะวันตก การชนกันนี้คงจะสิ้นสุดลงในช่วงอายุ Late Triassic

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Chapter 1 : Introduction

1.1 Introduction

Triassic sequences in Thailand are exposed in three main areas (Chonglakmani, 1981); in the north (Lampang-Phrae-Nan), west (Kanchanaburi-Mae Sariang), and in the south (Phang Nga-Songkhla) (Fig. 1.1). Among them the central north area, particularly in the Lampang and Phrae, has the best exposure in the country due to two highways which cross-cut nearly normal to the structural trend. The Triassic sequences in this area have been folded and faulted during the late Mesozoic and Cenozoic Eras, resulting in complex geological structures, steep dips and oroclinal "S-shaped" structural trends (Fig. 1.2). The rocks were first examined by Pitakpaivan (1955) and named the Lampang Group by Piyasin (1971,1972), during his compilation of the regional geological map. Many attempts to investigate the geology of this central north area have been made because it is a key area in discussions of the continent-continent collision between the Shan-Thai and Indochina terranes. Although there are a number of published papers concerning tectonic interpretations and paleontology (Bunopas, 1981; Bunopas and Vella, 1978, 1983; Chonglakmani, 1981,1983; Helmcke, 1982, 1983, 1984, 1985, 1986b; Hahn et al., 1986; Yanagida, 1988), the stratigraphy of the sequences is still unclear (Piyasin, 1972, 1975; Wolfart, 1987; and Chonglakmani and Kenvised, 1987a, b). There have been no studies published on facies analysis and sandstone provenance.

Recent detailed field studies, in addition to data from Chonglakmani (1981) and Chonglakmani and Kenvised (1987a, b), indicate that the Triassic sequence in the central north was, in fact deposited in two adjacent basins rather than in one basin, as previously believed. Each basin contains red beds, platform carbonates and turbidites. Each rock type comprises several lithofacies or microfacies. This thesis will propose new lithostratigraphic classification and depositional models for the Lampang Group and discuss their paleogeography and tectonic implications.

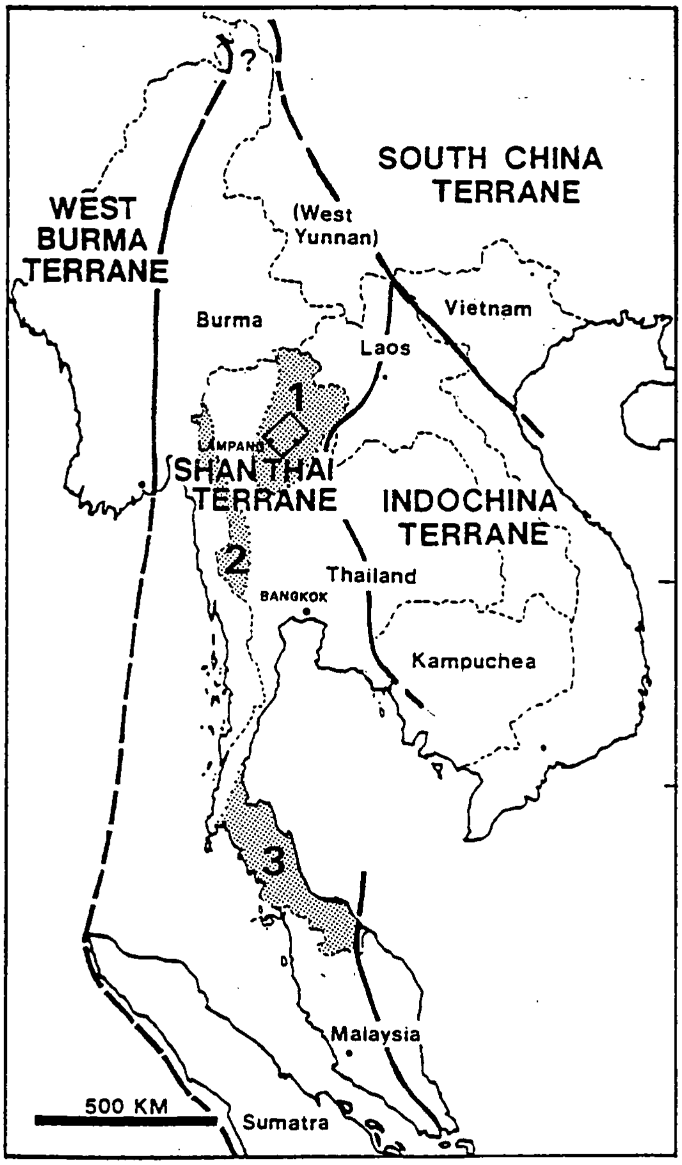


Fig. 1.1 Map showing major distribution of Triassic rocks in Thailand, the terrane boundaries of the Shan-Thai and Indochina, and their adjacent terranes (modified after Burrett et al., 1990); study area is shown in block symbol. 1 = Lampang - Phrae - Nan area, 2 = Kanchanaburi - Mae Sariang area, and 3 = Phang Nga - Songkhla area.

1.2 Regional Physiography and Geology

Physiography

Northern Thailand consists mainly of intermontane basins created by block faulting during the Cenozoic Era. As a result, almost all low-lying or intermontane basin areas were covered by Cenozoic sediments and all pre-Tertiary rocks including igneous rocks are exposed in mountainous areas. Central northern Thailand consists of two main subparallel Cenozoic basins running in an approximately NNE-SSW direction parallel to structural mountain trends that were oroclinally bent. The Cenozoic basins are Lampang-Mae Moh, to the west, and Phrae-Long, to the east. The Triassic Khun Tan granite batholith borders the western side of the study area. Among four main perennial river systems in northern Thailand, two are in this area, i.e., the Wang river on the Lampang basin and the Yom river on the Phrae basin.

Access to outcrops is very convenient, since two main highways, the Lampang-Denchai and Rong Kwang-Ngao highways, running NW-SE, cross-cut the structural trend. In addition, there are numerous cart tracks traversing into the mountainous areas, and thick jungles and dangerous wild animals have been removed.

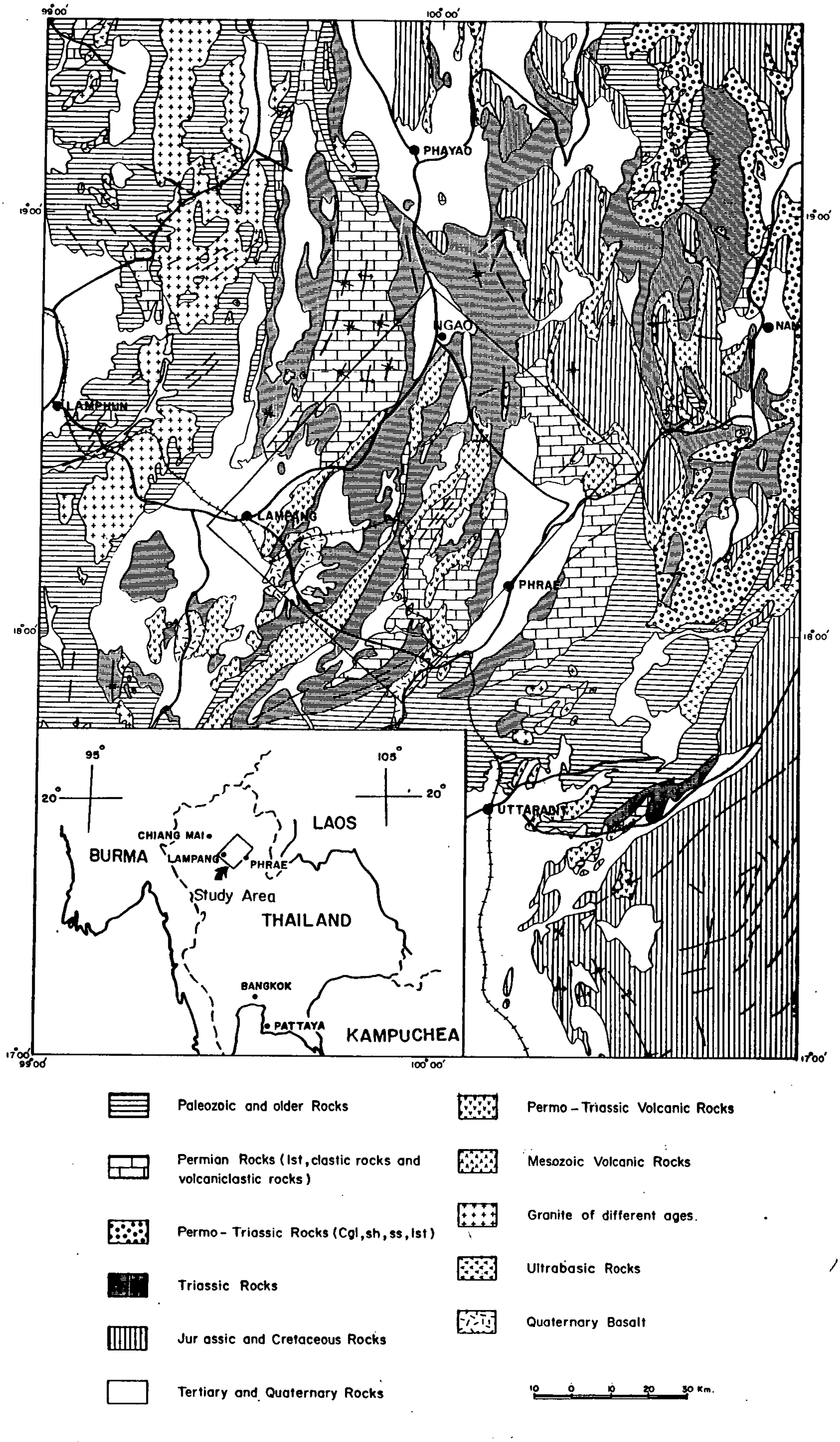
The central north of Thailand belongs to the tropical savanna area characterized by three seasons. Winter, with temperatures at night below 10° C, lasts from November to February. Summer covers the months of March through to June with temperatures during the day reaching 40° C. The rainy season, due to the southwest monsoon, occurs from July to October. Only the main roads are useful in the rainy season.

Regional Geology

The study area is located in the Sukhothai fold belt of the Shan-Thai terrane. This terrane is west of the Nan Suture Zone which was created by continent-continent collision with the Indochina terrane to the east (Bunopas, 1981; Hahn et al., 1986; and Panjasawatwong, 1991). Structural trends lie approximately NS direction that were oroclinally bent and folded, probably during Cretaceous and Paleogene Periods. The rocks were also faulted in the Cenozoic.

The oldest rocks in the central north of Thailand are called the Donchai Group (Piyasin, 1972). They consist mainly of low grade metamorphic rocks (green schist facies), i.e., phyllite, quartzo-feldspathic schist, chloritic phyllite, calcsilicate phyllite and slate. The Silurian-Devonian age of the Donchai Group was determined from its stratigraphic position below the Permian Ngao Group and the inferred Carboniferous

Fig. 1.2 Simplified regional geological map of central north Thailand showing the study area. Note the rocks are generally younger eastward direction with Jurassic and Cretaceous strata occurring mainly on the eastern side of the area. (Modified after Piyasin, 1972, 1974; Baum and Hahn, 1977).



99°00'
100°00'
19°00'
18°00'
17°00'
PHAYAO
NGAO
NAN
LAMPHUN
LAMPANG
PHRAE
UTTARADIT
95°
105°
20°
LAOS
CHIANG MAI
BURMA
LAMPANG
PHRAE
Study Area
THAILAND
BANGKOK
PATTAYA
KAMPUCHEA
Paleozoic and older Rocks
Permian Rocks (lst, clastic rocks and volcaniclastic rocks)
Permo - Triassic Rocks (Cgl, sh, ss, lst)
Triassic Rocks
Jurassic and Cretaceous Rocks
Tertiary and Quaternary Rocks
Permo - Triassic Volcanic Rocks
Mesozoic Volcanic Rocks
Granite of different ages.
Ultrabasic Rocks
Quaternary Basalt
10 0 10 20 30 Km.

Mae Tha Group (Piyasin, 1972, and Bunopas, 1981) and also from the degree of metamorphism and deformation which in the Donchai Group are higher than in the overlying strata. Clearly, metamorphism and deformation are not good criteria for dating the Donchai Group, and some parts are certainly of Permian age. The sheared marble north of Thoen District formerly mapped as the Donchai Group contains Permian fusulinids (Chaodumrong and Jeumthon, 1985). Wolfart (1987) suggested, on little or no evidence, that the Donchai is lower Permian.

The Mae Tha Group (Piyasin, 1972) unconformably overlies the Donchai Group and consists of alternating beds of quartzites, siliceous shales, feldspathic sandstones and some volcanics. No fossils have been reported. The Carboniferous age of this group is inferred from its stratigraphic position below the fossiliferous Permian Ngao Group. Both the Donchai and Mae Tha Groups are exposed only at the flanks of the study area. According to the drill-hole data of the Defense Energy Department in the Lampang Tertiary Basin, and of the Electricity Generating Authority of Thailand in the Mae Moh Tertiary Basin, the basement rocks belong to the Lampang Group.

The Ngao Group (Bunopas, 1981) has scattered exposure throughout the study area (Piyasin, 1972; Fontaine and Suteetorn, 1986; and Yanagida, 1988), and consists of three formations. The lowest formation, named Kiu Lom (Piyasin, 1972), consists mainly of andesites, rhyolites, tuff, agglomerates, sandstones and shales with minor limestone beds, and contains lower Permian fossils. The middle formation is Pha Huat (Piyasin, 1972) which consists mainly of shallow platform limestones and commonly contains middle to upper Permian fossils (Piyasin, 1972; Yanagida, 1988). The upper formation, Huai Thak (Piyasin, 1972), consists mainly of shale, sandstones, conglomerates, and commonly contains volcanic rock fragments and upper Permian fossils. Unconformably overlying the Ngao Group is the "Permo-Triassic volcanic rock" which receives its age from its stratigraphic position. No age-dating has been done. Some volcanic trends are likely to belong to a younger age. The volcanics are widespread in several NE-SW subparallel trends between the towns of Lampang and Phrae (Fig. 1.2) and consist mainly of calc-alkali rocks, rhyolites, andesites, tuffs and agglomerates.

The Triassic Lampang Group formed in 2 adjacent sub-basins that contain similar lithology and lithologic sequences but are different in age. It unconformably overlies "Permo-Triassic volcanic rocks". It both conformably and unconformably overlies and underlies the Permian strata and the inferred Jurassic red beds, respectively. The overlying conformable contact occurs mainly in the central area (graben) of the younger depositional basin, particularly in the area east of Ngao and Phayao (Hahn et al., 1986; Chonglakmani and Kenvised, 1986; V. Tansuwan, pers. comm., 1990). Ages for all red beds are poorly known. Most are suggested on the basis of their stratigraphic position. Another major unconformity developed during the Cretaceous to middle Tertiary interval, and no Cretaceous to middle Tertiary fossils have been found in this area. The youngest unconformity is commonly placed at the inferred Tertiary-Quaternary boundary.

1.3 Previous Work

Three main topics which are most important but unclear, i.e., the stratigraphy, sedimentology, and tectonics of the Lampang Group, will be emphasized and discussed under this heading.

Stratigraphy

It is well known that the sedimentary sequences of the Lampang Group in central north Thailand, particularly in the Lampang and Phrae areas, are similar, consisting of red beds and limestones topped by "flysch" sediment (Piyasin, 1972, 1975; Baum and Hahn, 1977). However, their ages are very different; those in the Phrae area being younger (Chonglakmani, 1981). Recently, most of these areas have been mapped at a scale of 1:50 000. There are now two sharply contrasting lithostratigraphic classifications in existence (Table 1.1). One scheme includes the strata in the Lampang and Phrae areas in the same lithostratigraphic unit, according to the assumption of Piyasin (1972) and Chonglakmani (1981) that these strata were deposited in the same depositional cycle (Charoenpravat et al., 1986; Sukvattananunt and Paksamut, 1986; Wolfart, 1987; and Charoenpravat et al., 1987). In detail, however, the terminologies of Piyasin (1972) and Chonglakmani (1981) are dissimilar. The other scheme is new and considers the sedimentary sequence in the Phrae area as a separate younger depositional cycle lying on that in the Lampang area (Chonglakmani and Kenvised, 1987a, b). The intensive detailed field investigation covering the whole area in this study confirms the latter scheme (Table 1.1). Unfortunately, most previous published papers (Bunopas, 1981; Helmcke, 1985, 1986b; Wolfart, 1987; and Chonglakmani and Helmcke, 1989) follow the former nomenclatural scheme which brought an imprecise interpretation and a confusing terminology to the regional stratigraphy.

Table 1.1 Lithostratigraphic nomenclature development of the Lampang Group of Thailand

<table>
<tr><th colspan="2" rowspan="2">Piyasin 1972</th><th colspan="2" rowspan="2">Liengsakul 1979</th><th colspan="2" rowspan="2">Chonglakmani 1981</th><th colspan="2" rowspan="2">Chonglakmani and Tiyapun 1985</th><th colspan="2" rowspan="2">Wolfart 1987</th><th colspan="2" rowspan="2">Chonglakmani and Kenvised 1987 a,b</th><th colspan="3">THIS STUDY</th></tr>
<tr><th colspan="2">Sop Prap-Ngao- / Chae Hom-Pha Yao- / Lampang Chiang Rai "Lampang Subbasin"</th><th>Phayao-Ngao Long-Wang Chin "Phrae Subbasin"</th></tr>
<tr><td colspan="2" rowspan="3"></td><td colspan="2" rowspan="3"></td><td colspan="2" rowspan="3"></td><td colspan="2">Khun Huai Ri</td><td colspan="2" rowspan="5"></td><td colspan="2" rowspan="2">Tr 8</td><td rowspan="8">L A M P A N G</td><td rowspan="3"></td><td rowspan="2">Wang Chin Fm: Phu Tap, Huai Chan, Mae Lu SS, Phu Tap</td></tr>
<tr><td rowspan="2"></td><td>Mae Tum</td></tr>
<tr><td>Kang Pla</td><td colspan="2">Tr 7</td><td>Kang Pla Fm</td></tr>
<tr><td rowspan="5">L A M P A N G</td><td>Pha Daeng</td><td colspan="2">Pha Daeng</td><td colspan="2">Pha Daeng</td><td>Thung Po</td><td>Mae Thang</td><td rowspan="5">L A M P A N G</td><td>Pha Daeng</td><td colspan="2">Pha Daeng Fm</td></tr>
<tr><td>Doi Chang</td><td rowspan="4">L A M P A N G</td><td>Doi Chang</td><td rowspan="4">L A M P A N G</td><td>Doi Long</td><td colspan="2" rowspan="4"></td><td colspan="2"></td><td>Doi Long</td><td>Doi Long Fm</td><td rowspan="4"></td></tr>
<tr><td>Hong Hoi</td><td>Hong Hoi</td><td>Hong Hoi</td><td rowspan="3">L A M P A N G</td><td>Wang Chin</td><td>Hong Hoi</td><td>Hong Hoi Fm; Mae Dum SS; Huai Muang; Tha Si</td></tr>
<tr><td>Pha Kan</td><td>Pha Kan</td><td>Doi Chang</td><td>Pha Kan</td><td>Doi Chang</td><td>Pha Kan Fm; Muang Kham; Chang Garb; Cave Temple; Wiang Sawan</td></tr>
<tr><td>Phra That</td><td>Phra That</td><td>Phra That</td><td>Phra That
Pha Lak Mun</td><td>Phra That</td><td>Phra That Fm</td></tr>
</table>

Sedimentology

Although there are a number of published papers in this area (Bunopas, 1976, 1981; Bunopas and Vella, 1983; Chonglakmani, 1983; Helmcke, 1985, 1986 a, b; Wolfart, 1987; and Chonglakmani and Helmcke, 1989), no facies analysis of either carbonates or siliciclastics has been published. Previous interpretation of depositional environments was, therefore only made in broad terms. In the following paragraphs the three main rock types of the Lampang Group, i.e., carbonates, marine turbidites, and red beds will be discussed.

The shallow marine carbonate platform was widely suggested for the Lampang carbonates based mainly on an occurrence of abundant oncolites and some oolites (Piyasin, 1972; Chonglakmani, 1972, 1981; Bunopas, 1981; Helmcke, 1985), although the oncolites are mainly restricted to the Pha Kan Formation. Few oncolites are found in the younger Doi Long and Kang Pla Formations. Depositional environments of the Lampang carbonates are no doubt mainly shallow marine, even though allodapic limestone also occurs and was first recognized in this study. However, the carbonates formed in a variety of depositional environments which can be interpreted in terms of three depositional models, namely ramp, drowned ramp, and regression platforms.

Mudstones and interbedded sandstones of the Hong Hoi and Wang Chin Formations have been interpreted in different ways: flysch and pelagic sediments (Chonglakmani, 1972, 1981), forearc sediments (Bunopas, 1981; Sengör, 1984), post-collisional sediments (Helmcke, 1984; Chonglakmani and Helmcke, 1989), and neritic sediments (Hahn and Siebenhuner, 1982). Although these rocks are not identical to the "classical turbidite" (Walker, 1984) because they lack prominent flute structures on the basal Bouma Ta, they certainly formed by turbidity current; therefore they are turbidites. Turbidites can form in both shallow and deep water environments but they are not commonly preserved in shallow environments due to subsequent wave and current actions (Walker, 1984). The turbidites were deposited in submarine fan environments, as demonstrated in Chapter 4 of this thesis.

The red beds of the Phra That and Pha Daeng Formations have been paid the least attention. Continental origin appears to be widely accepted, based mainly on their oxidation characteristics (Piyasin, 1972; Bunopas, 1981). Their depositional environment was previously thought to be fluviatile but this is unlikely due to the rarity of sedimentary structural characteristics of the fluvial such as channels, and point bar cross bedding. Of particular interest is the presence of turbidites with associated mudcracks in red beds of the Pha Daeng Formation. The red beds were deposited in a fan delta environment, as is demonstrated in Chapter 5 of this thesis.

Tectonics

Many of the published papers concerning this area have focused on the collision between the Shan-Thai and Indochina terranes. However, there have been long-standing controversies over the timing of suturing and the directions of subduction.

Opinions vary as to the timing of suturing. These are Devono-Carboniferous (Hahn et al., 1986; Alterman, in press), middle to late Carboniferous (Wolfart, 1987), middle Permian (Helmcke and Lindenberg, 1983; Helmcke, 1985), late Permian (Burton, 1984), late Permian to early Triassic (Thanasuthipitak, 1978; Cooper et al., 1989; Sattayarak et al., 1989; Hayashi, 1989; Piyasin, 1991), and middle to late Triassic (Bunopas and Vella, 1978, 1983; Gatinsky et al., 1978; Asnachinda, 1978; Macdonald and Barr, 1978; Bunopas, 1981, 1985; Chonglakmani, 1981; Sengör, 1984; Hutchison, 1989; Hada, 1990; Chauviroj, 1990; and Panjasawatwong, 1991).

Prior to the collision, westward subduction beneath Shan-Thai was advocated by Bunopas and Vella (1978), Chantaramee (1978), Asnachinda (1978), Bunopas (1981), Sengör (1984), Barr and Macdonald (1987) and Hayashi (1989) based on the wide distribution of volcanics in central north Thailand and on the eastward structural vergence. Eastward subduction beneath Indochina, based on the position of S-and I-type intrusive rocks, was proposed by Beckinsale et al. (1979), and Cooper et al. (1989).

Bunopas (1981) considered sediments of the Lampang Group to have been deposited in the interarc and forearc basins that were created by the westward subduction of the Indochina terrane beneath the Shan-Thai terrane, whereas Helmcke and Lindenberg (1983), Helmcke (1985,1986 a, b) and Chonglakmani and Helmcke (1989) interpreted them as post-orogenic sediments occurring in the shallow-water of a rapidly subsiding basin. Chonglakmani (1981) subdivided the Lampang clastics, on paleontological evidence, into shallow-water and deep-water facies. In the Lampang-Phrae area, the deep-water facies were deposited mainly during the late Ladinian to early Carnian and locally during the middle Carnian to early Norian.

1.4 Methods of Study

A total of eleven months' field work was undertaken in 1987, 1988 and 1990. Twenty-four sections were measured and hundreds of reconnaissance locations were investigated concentrating on an area of approximately 3,000 square km (main study area) in the Lampang, Phrae and Phayao Provinces (Fig. 1.2). Lithostratigraphic nomenclature of the Lampang Group is proposed according to the International Stratigraphic Guide (Hedberg,1976) and following the suggestions of Haile (1987).

Facies have been distinguished by using lithology, sedimentary structures and fossil types. Where available, other features such as geometry and paleocurrents are also employed. Carbonates, in particular, are defined as microfacies following Wilson (1975) and Flügel (1982). The petrographic classification used throughout this thesis is that of Dunham (1962) for carbonate rocks and that of Folk (1974) for siliciclastic rocks. About 450 samples of carbonates have been examined using conventional petrographical and cathodoluminescent techniques. Most are made to the standard large size of polished thin sections (5 x 7.5 cm), for a better view of allochems. Carbonate thin sections were stained with alizarin red-S and potassium ferricyanide to distinguish calcite, dolomite and ferroan carbonate (Dickson, 1966; Evamy, 1969). Sandstone thin sections, almost all cut to the small standard size (2.6 x 7.5 cm) and polished, were stained with HF, sodium cobaltinitrite, barium chloride and amaranth to reveal K-feldspar and plagioclase (Norman, 1974). Provenances of sandstone were investigated in three different ways. Detrital grains in sandstone composition of fifty-six thin sections were counted by using Gazzi-Dickinson point-counting method (Ingersoll et al., 1984), then plotted against discriminating diagrams of Dickinson (1985), and Ingersoll and Suczek, 1979. The second provenance approach comes from rare earth abundances in turbidite sandstones, following Bhatia (1985).

1.5 Objectives of the Study

The purpose of this thesis is to:

1) Revise the stratigraphic nomenclature of the Lampang Group.

2) Assess carbonate microfacies and construct depositional models for the Lampang carbonates : the Pha Kan, Doi Long and Kang Pla Formations.

3) Assess siliciclastic lithofacies and construct depositional models for the Hong Hoi, Pha Daeng, and Wang Chin Formations.

4) Assess provenances of sandstones, particularly the turbidites within the Lampang Group.

5) Assess and construct models for the evolution of the Lampang Group.

6) Discussion on the paleogeography and tectonic setting of the Lampang Group and its relationship to the collision between the Shan-Thai and Indochina terranes.

Chapter 2 : Lithostratigraphy of the Lampang Group

2.1 Introduction

Recent detailed field studies on stratigraphy and sedimentology show that the Lampang Group in the central north of Thailand formed in two adjacent basins: the Lampang sub-basin in the west, and the Phrae sub-basin in the east. This interpretation contrasts sharply with the single depositional basin model of previous workers (Piyasin, 1972; Chonglakmani, 1972, 1981). The Lampang sub-basin takes in the Sop Prap, Lampang, Chae Hom, Wang Nua, Phayao and Chiangrai areas, while the Phrae sub-basin takes in the Wang Chin, Phrae, Long, Song, Ngao, Phayao and Chiangrai areas. These two sub-basins are separated in the south by the Doi Luang-Khun Khiat Range that consists of volcanics of possibly Permo-Triassic age (Fig. 2.1). Sediments and sedimentary sequences of these two sub-basins are strikingly similar, consisting mainly of red beds, platform carbonates and turbidites; but their ages are very different.

There are two popular stratigraphic nomenclatural schemes for the Lampang Group; those of Piyasin(1972) and Chonglakmani(1981). However, these two schemes considered the sediments of the Lampang Group within the Lampang and Phrae areas as having been formed with an eastward migration of the depocenter through time. Therefore, the same rock types such as red beds or carbonates in these two sub-basins were regarded as the same lithostratigraphic units (Table 1.1).

The two-basin concept has been discussed among Thai geologists since 1981 and was first introduced by Dr. Chongpan Chonglakmani. However, little evidence for the two-basin model has been published (Chonglakmani and Tiyapun, 1985; and Chonglakmani and Kenvised, 1987 a, b).

In order to establish the lithostratigraphy of the Lampang Group (Fig. 2.1 and Table 1.1), 24 sections were measured in detail. Furthermore, hundreds of reconnaissance localities were investigated. Lithostratigraphic units are described, defined or redefined as suggested in the International Stratigraphic Guide (Hedberg, 1976). Early, middle, and late are used for geochronological or time units (periods, epochs, ages, etc.) to describe "the time of occurrence of historical events" (Haile, 1987) such as periods of erosion, transgression, folding, faulting, faunal extinction, age of fossil, oil generation and migration, and time of events shown on graphical representations of geological history. Lower, middle, and upper, on the other hand, are used for chronostratigraphic or time-rock units (system, series, stage, etc.) to describe the age of rock, formation, biostratigraphic zone, unconformity, and graphic representation (e.g., stratigraphic correlation diagram and well log (Haile, 1987). Unless the period/ system subdivisions have been defined by international agreement the term early (lower), middle, and late (upper) are written with a lower case initial in order to denote informality. Note that the names of highways or roads (used as the reference for the kilometer-marker-post system) in this study commence with the name of the town from which distances are measured, except where the highways or roads have formal names.

2.2 Evidence for the "Adjacent Basin" model

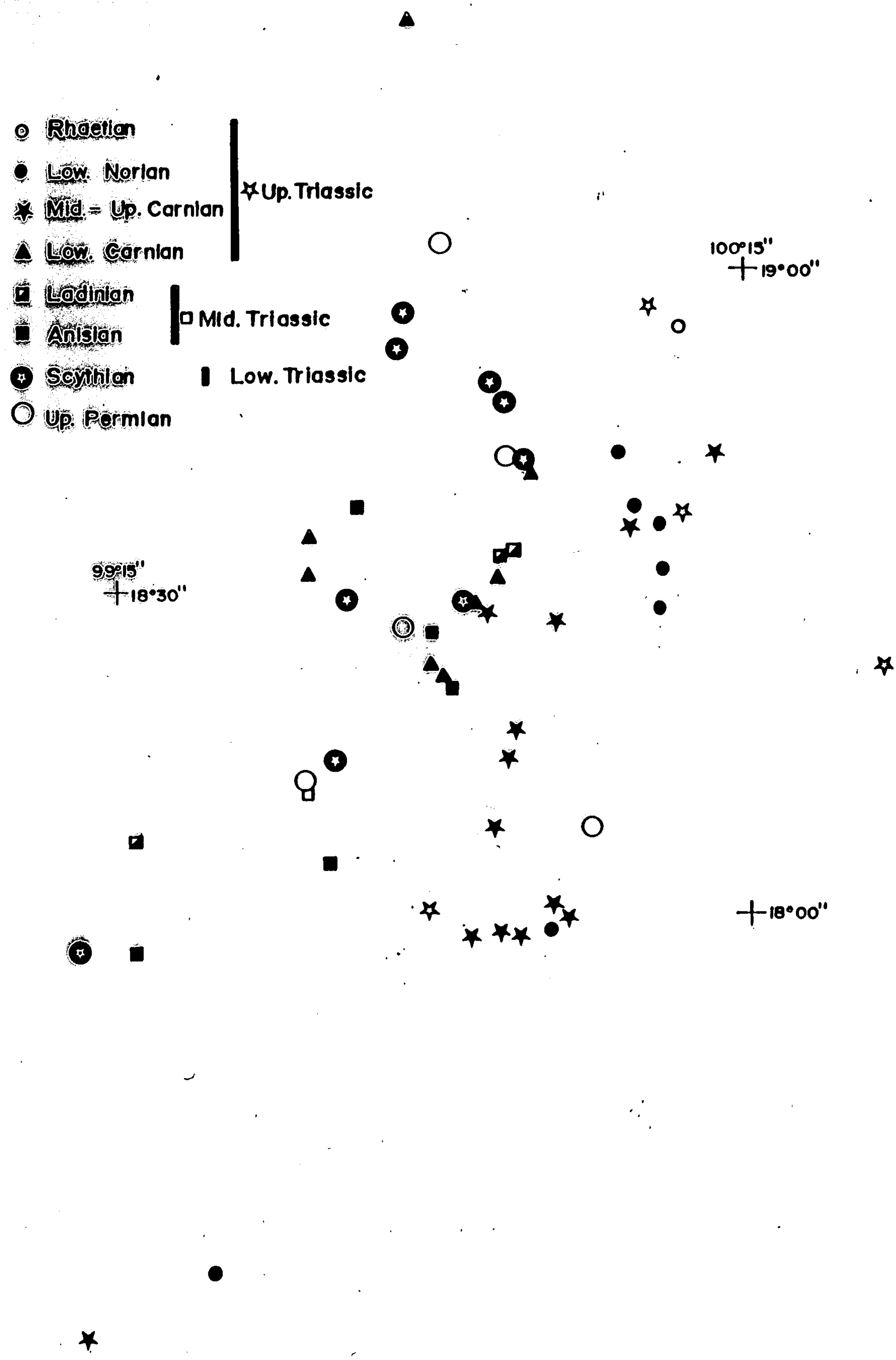
There are several lines of evidence that support the "adjacent basin" model, as follows.

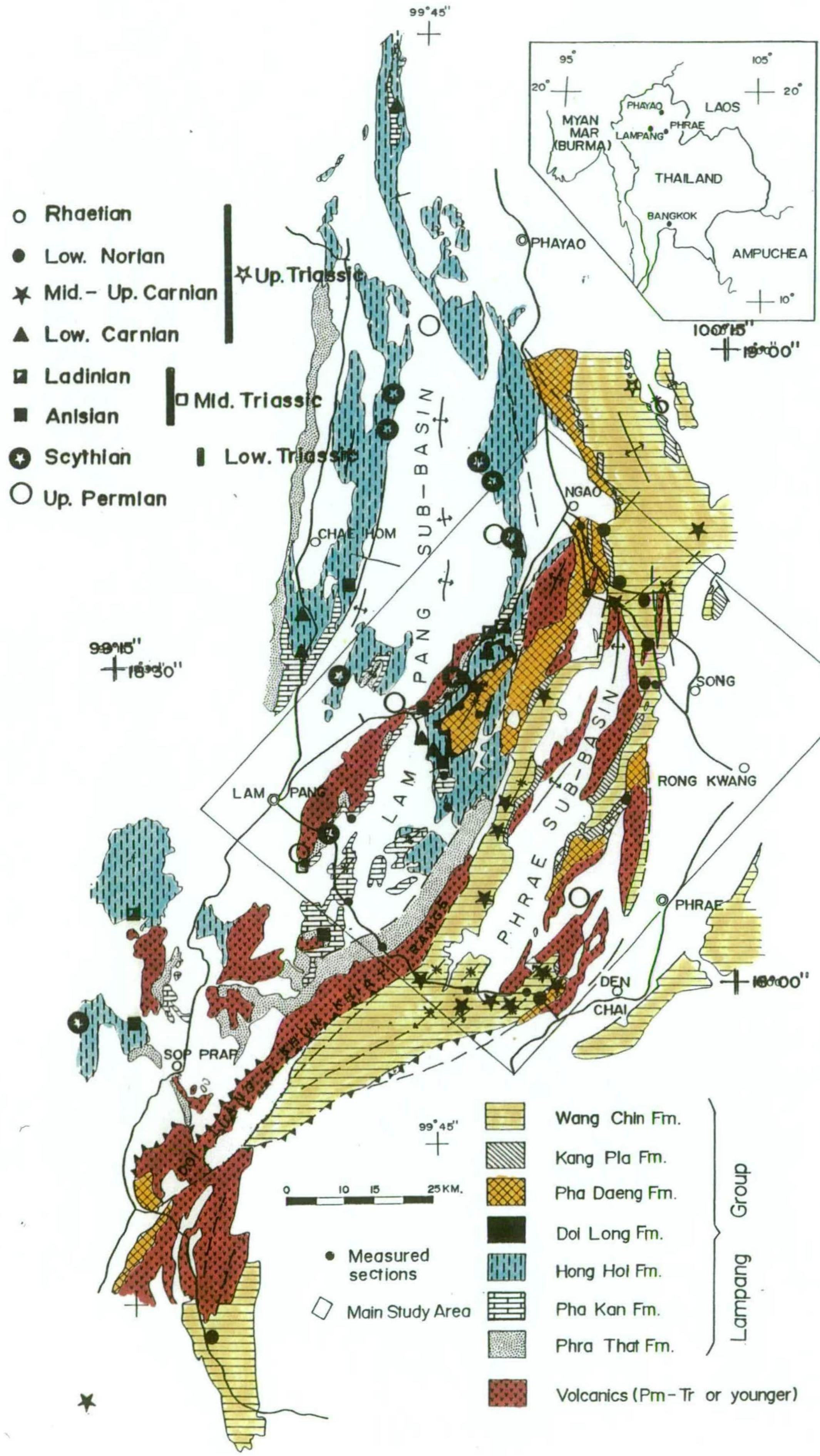
1) Sedimentation in the two areas was initiated at different times. Paleontological evidence (bivalves, ammonoids and conodonts) suggests that the Lampang sub-basin, containing *Daonella* , *Paratrachyceras* , *Costatoria* , and *Claraia* , was formed much earlier during early Triassic (Griesbachian) to early late Triassic (middle Carnian) whereas the Phrae sub-basin contains mainly *Halobia* (Chonglakmani, 1981) indicating early late Triassic (middle Carnian) to late Triassic (early Norian).

2) One of the most critical clues for unravelling the problem is the stratigraphic placement of the red beds along the Rong Kwang-Ngao highway in the Ngao District (occurring in the Lampang sub-basin, and placed in the Hong Hoi Formation by Piyasin,1972; and in the Mae Thang Formation by Chonglakmani and Tiyapun,1985), and the red beds in the Phrae sub-basin (mapped as the Phra That Formation by Piyasin, 1972). Evidence given below suggests that the red beds in these two areas in fact belong to the Pha Daeng Formation.

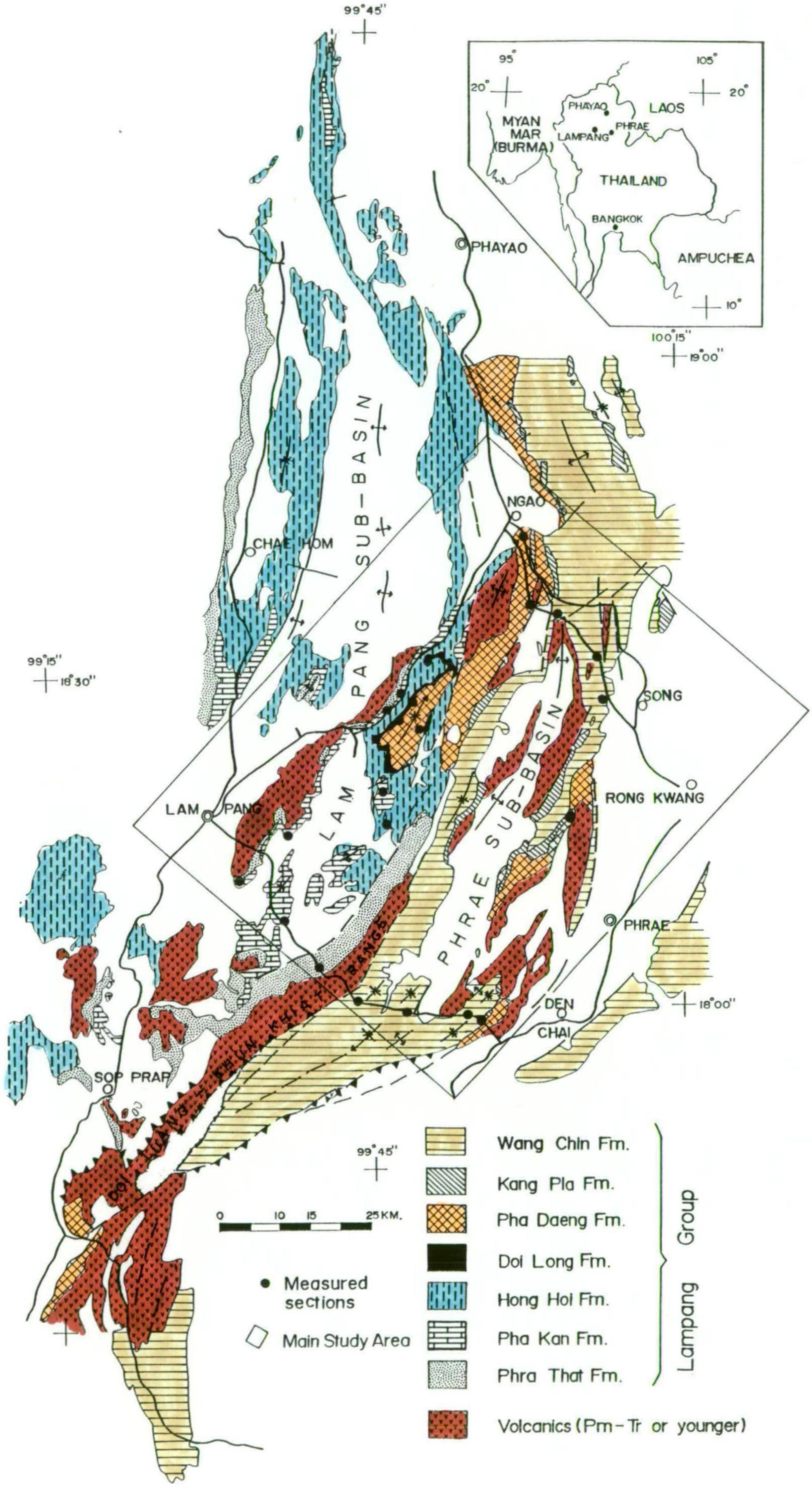
Fig. 2.1 Geological map of the Lampang Group in central north Thailand showing the aerial distribution of the constituent formations, the study area and the location of the measured sections. Note the distribution of each formation within the sub-basins. (Compiled from Piyasin, 1972, 1974; Baum and Hahn, 1977; Tansathien, 1982; Chonglakmani and Tiyapun, 1985; Tansuwan and Jindasute, 1985; Charoenpravat et al., 1986; Chonglakmani and Kenvised, 1986, 1987 a, b; Sukvattananunt and Paksamut, 1986; Wolfart, 1987; and Charoenpravat et al., 1987).

Transparency : Distribution of rock ages from dated fossils in the Lampang Group and the adjacent strata. Note the rocks younging eastward direction. Data from Chonglakmani, 1981; Chonglakmani and Kenvised, 1986; Yanagida, 1988; Dr. C.F. Burrett , unpubl. data; Dr. S.P. Carey, unplub. data; and this study.


Rhaetian
Low. Norian
Mid. = Up. Carnian
Low. Carnian
Up. Triassic
Ladinian
Anisian
Mid. Triassic
Scythian
Low. Triassic
Up. Permian
100°15"
19°00"
99°15"
18°30"
18°00"



Rhaetian
Low. Norian
Mid.- Up. Carnian
Low. Carnian
Up. Triassic
Ladinian
Anisian
Mid. Triassic
Scythian
Low. Triassic
Up. Permian
99°45''
99°15''
18°30''
100°15''
19°00''
18°00''
95°
105°
20°
10°
MYAN MAR (BURMA)
PHAYAO
LAMPANG
PHRAE
LAOS
THAILAND
BANGKOK
AMPUCHEA
CHAE HOM
NGAO
SONG
RONG KWANG
LAM PANG
PHRAE
DEN CHAI
SOP PRAP
LAM PANG SUB-BASIN
PHRAE SUB-BASIN
0 10 15 25 KM.
Measured sections
Main Study Area
Wang Chin Fm.
Kang Pla Fm.
Pha Daeng Fm.
Doi Long Fm.
Hong Hoi Fm.
Pha Kan Fm.
Phra That Fm.
Lampang Group
Volcanics (Pm-Tr or younger)


99°45''
95°
105°
20°
20°
MYAN MAR (BURMA)
PHAYAO
LAOS
LAMPANG
PHRAE
THAILAND
BANGKOK
AMPUCHEA
10°
PHAYAO
100°15''
19°00''
PANG SUB-BASIN
LAM
NGAO
CHAE HOM
99°15''
18°30''
SONG
LAM PANG
RONG KWANG
PHRAE SUB-BASIN
PHRAE
DEN CHAI
18°00''
SOP PRAP
DOI LUANG - PHI PAN NAM RANGE
99°45''
0 10 15 25 KM.
Measured sections
Main Study Area
Wang Chin Fm.
Kang Pla Fm.
Pha Daeng Fm.
Doi Long Fm.
Hong Hoi Fm.
Pha Kan Fm.
Phra That Fm.
Lampang Group
Volcanics (Pm - Tr or younger)

3) Stratigraphically, the Pha Daeng red beds along the Rong Kwang-Ngao highway can be traced, in the field, southward to the type section of the Pha Daeng Formation at Doi Pha Daeng. The red beds at both locations are similar in their lithologies (plagioclase-rich sandstones) and paleocurrent directions. Furthermore, their grain size and sandstone bed thicknesses decrease northward, consistent with the paleocurrent direction. The red beds at the highway were also suggested as belonging to the Pha Daeng Formation by Bunopas (1981) and Piyasin (pers. comm., 1987).

4) The Pha Daeng red beds along the highway (3) are conformably overlain by limestones of the Kang Pla Formation (the Khun Huai Ri Formation of Chonglakmani and Tiyapun, 1985) which is exposed in the Phrae sub-basin. These limestones can be correlated southeastwards, on the basis of their structural trend, to the road-cut exposure at km 45.5 on the Rong Kwang-Ngao highway (Phrae sub-basin; for details see 2.10.1). Here, the Kang Pla Formation is conformably underlain by gray beds and red beds containing shallow marine benthic fauna (Chonglakmani,1981) of the Pha Daeng Formation (mapped as the Phra That Formation by Piyasin, 1972, 1980; Chonglakmani, 1981), and overlain by gray mudstones of the Wang Chin Formation.

5) Southwards, a similar succession (red beds passing upward to limestones and turbidites) as at km 45.5 on the Rong Kwang-Ngao highway occurs at Huai Pha Bong (Phrae sub-basin, grid reference 137218 sheet 5045-4 Amphoe Song, 5 km east of Ban Paen or 33 km south of the highway location). The red beds here, formerly mapped as the Phra That Formation (Piyasin, 1972), are similar to the red beds of the Pha Daeng Formation at the type location in their lithologies and age. Therefore, they are here interpreted to belong to the Pha Daeng Formation.

6) Evidence from fossils and sedimentary facies (red beds, coal beds and benthic fauna) indicates that during middle Carnian continental to shallow marine sediments of the Pha Daeng Formation were deposited at least in an area, approximate E-W direction, between Doi Pha Daeng (Lampang sub-basin) and km 45.4 on the Rong Kwang-Ngao highway (Phrae sub-basin).

7) Evidence in (6) also implies that during middle Carnian the Lampang sub-basin was relatively rising while the Phrae sub-basin was subsiding as suggested by deeper marine facies in the southern part of the Phrae sub-basin. In addition, the pronounced vertical regressive sequence in the Lampang sub-basin, from marine turbidites (Hong Hoi Fm) to platform carbonates (Doi Long Fm) and red beds (Pha Daeng Fm), implies either uplift of the sub-basin or relative sea level fall. Furthermore, the transitional contact between the gray beds of the Hong Hoi Formation and the overlying red beds of the Pha Daeng Formation, at the road to Mon Talai Nok temple, 3.5 km SE of Ngao, is not only consistent with the general regressive nature of the sequence but also indicates an absence or limited distribution of the Doi Long Formation.

8) Evidence from fossils indicates that ages of rocks in the northern part of the two sub-basins change gradually while in the southern part an age gap occurs

9) Jurassic rocks in the Lampang sub-basin are rare and unconformably underlain by the Lampang Group while in the Phrae sub-basin they are abundant and conformably overlie the Lampang Group (Chonglakmani and Tiyapun,1985). Evidence in 8 and 9 supports localized uplift and subsidence, although this movement may also be the result of later tectonic event.

10) Lithofacies associations of the Pha Daeng Formation indicate a fan-delta depositional environment that implies the existence of topographic relief (details see CH-5).

11) The Lampang sub-basin is bounded by the red beds of the Phra That Formation. This situation favors an extensional style of basin formation rather than basin depocenter migration, as previously presumed. Furthermore, the distribution of rock ages in the Lampang sub-basin shows that the oldest rocks (west of Ngao and east of Chae Hom) occur in the central part of the elongated basin, and the younger toward the flanks (Fig. 2.1-Transparency). This distribution suggests an original confined basin.

There is now little doubt that the Triassic sequences formed in two adjacent basins. Therefore, the lithostratigraphic units in the two basins should be given different names.

2.3 Previous lithostratigraphic nomenclature : Discussion

The traditional lithostratigraphic nomenclatural schemes used for the Lampang Group are those of Piyasin(1972) and Chonglakmani(1981). The former author named the Lampang Group and recognized 5 formations, in ascending order as Phra That, Pha Kan, Hong Hoi, Doi Chang, and Pha Daeng. Chonglakmani(1981) revised the Lampang Group. He recognized 4 formations and reapplied their names as follows (in ascending order): Phra That, Doi Chang, Hong Hoi, and Doi Long; he excluded the Pha Daeng Formation from the Lampang Group (Table 1.1). It should be emphasized that these two authors considered the sediments in the Lampang and Phrae sub-basins as being lithostratigraphic equivalents, a view that is challenged in this study. It is suggested that usage of their formation names should be restricted to the Lampang Sub-basin where they were originally mapped and defined.

The nomenclature of the two carbonate formations within the Lampang Group in the Lampang sub-basin is in a very confusing state (Table 1.1) with the names Pha Kan, Doi Chang, and Doi Long being used in a variety of ways. Pitakpaivan (1955) first mapped the rock sequences at Doi Chang, east of the Mae Moh Lignite Mine. He informally named the "Pha Kap limestone, Calcareous sandstone and Oolite, Fossiliferous limestone, Limestone conglomerate, Doi Chang shale and sandstone, and Doi Chang limestone". Piyasin (1972), on compiling the geology of this area, used another type locality and proposed the Pha Kan Formation that is equivalent to Pitakpaivan's names. However, Piyasin (1972) also used Doi Chang for the name of another, younger, limestone formation (Table 1.1). Chonglakmani (1981) followed Pitakpaivan (1955) and substituted the names, Doi Long and Doi Chang for the Doi Chang and Pha Kan Formations, respectively, of Piyasin (1972) (Table 1.1). Because of the confusion surrounding the name Doi Chang and in accordance with the international stratigraphic guide (Hedberg,1976, p 19,40) this name is abandoned in this study. The names Pha Kan and Doi Long are used for the lower and upper limestone formations, respectively, in the Lampang sub-basin.

Chonglakmani (1981,1983) separated the Pha Daeng Formation from the Lampang Group. His reasons were based mainly on the red coloration and the unconformity at the base of the Pha Daeng Formation, as evidenced by limestone conglomerates. However, this limestone conglomerate has a limited distribution, occurring mainly at Doi Pha Bong. The unconformity is considered here as local rather than regional. On the other hand, the lithology of the Pha Daeng Formation is similar to that of the Phra That Formation which is the lowest formation of the Lampang Group. Therefore the Pha Daeng Formation is considered as belonging to the Lampang Group. This conclusion agrees with that of Chonglakmani and Kenvised (1987 a, b).

2.4 Proposed lithostratigraphic nomenclature for the Lampang Group

The proposed lithostratigraphic nomenclature of the Lampang Group is shown in Table 1.1 and Figs. 2.1 and 2.2 and details are given below. Twenty four detailed locations, separated into 2 sections for the Phra That, 6 for Pha Kan, 2 for Hong Hoi, 5 for Doi Long, 7 for Pha Daeng, 2 for Kang Pla, and 7 sections for the Wang Chin Formation, were measured. Furthermore, hundreds of reconnaissance localities were investigated. Stratigraphic symbols used in this study are summarized in Figure 2.3.

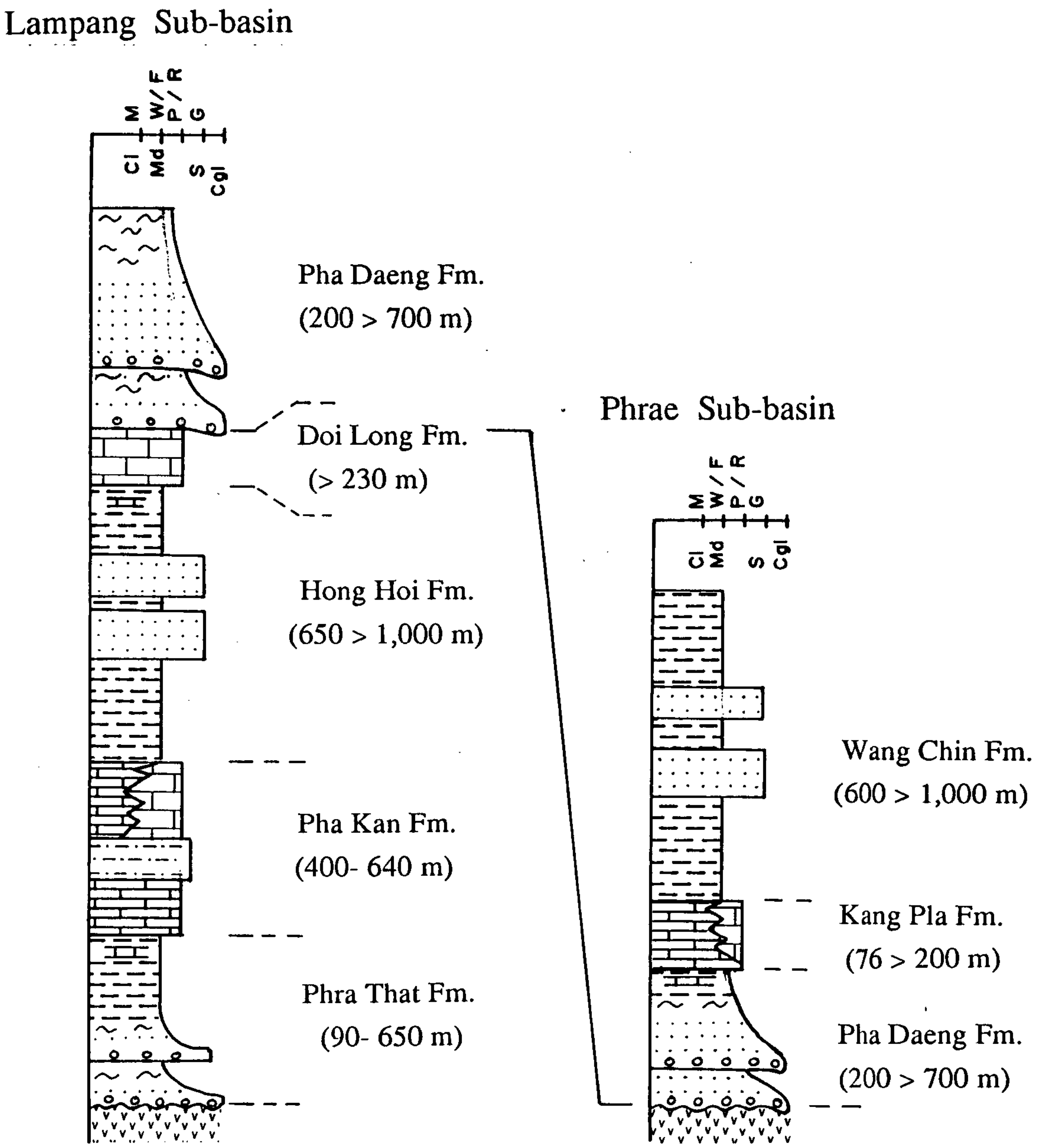


Fig. 2.2 Generalized lithostratigraphy of the Lampang Group and thickness of the formations.

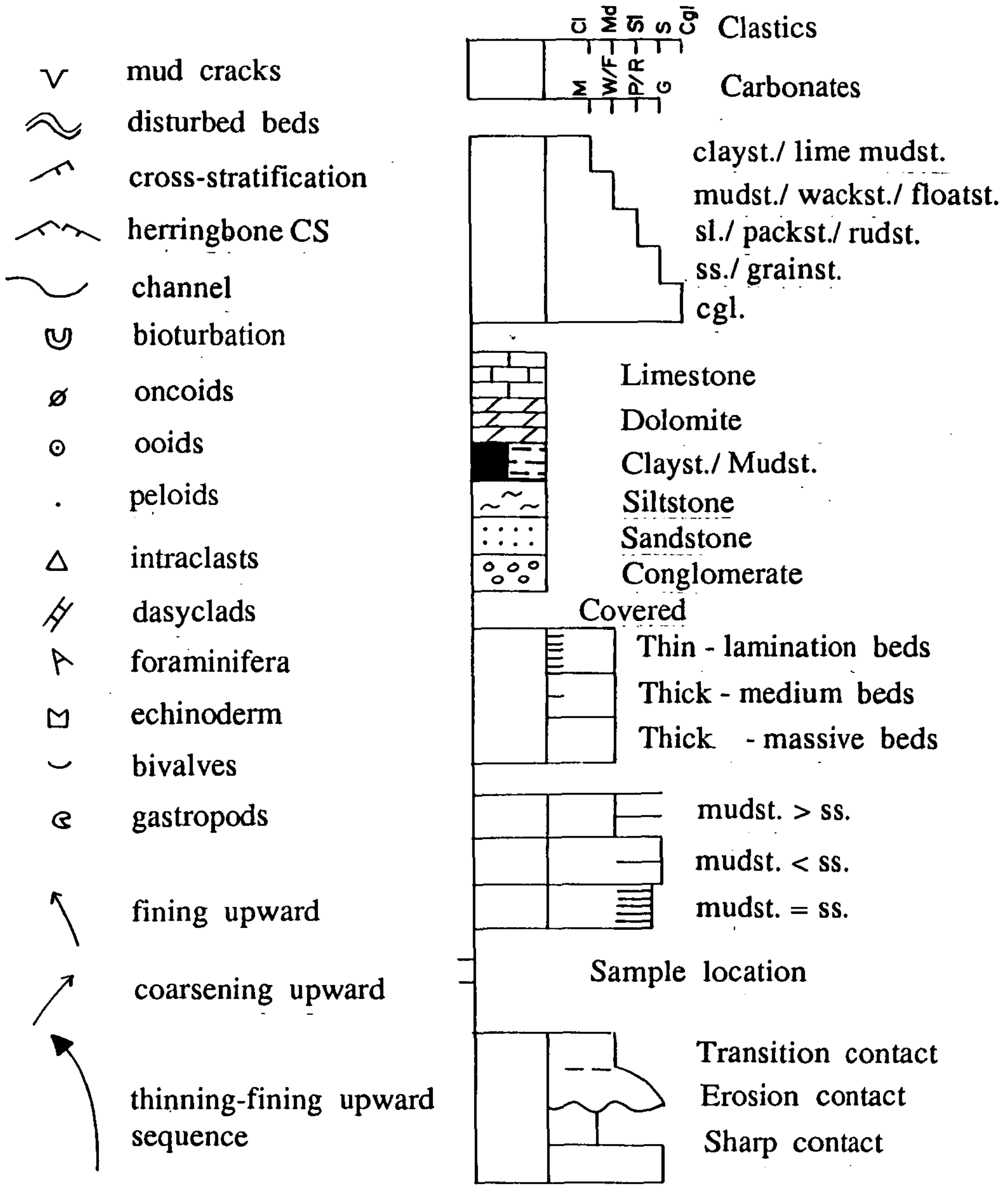


Fig. 2.3 Key to stratigraphic symbols used in this study. The most abundant types will be indicated by a double symbol and common types by a single symbol.

Definition : The Lampang Group is a sequence of red beds, carbonates and turbidites and comprises seven formations. It occurs mainly in two adjacent basins, named the Lampang and Phrae sub-basins, in the central-north of Thailand. In most areas, it unconformably overlies inferred Permo-Triassic volcanics and both unconformably and conformably overlies the Permian strata. The conformable contacts occur particularly in the Lampang sub-basin. It is both conformably and unconformably overlain by red beds of possibly Jurassic age. The maximum thickness is estimated at 3000 m and 2000 m in the Lampang and Phrae sub-basins, respectively.

Lithology : The Phra That and Pha Daeng Formations consist mainly of red conglomerates, sandstones, siltstone and mudstone commonly showing fining upward sequences. Wherever they are overlain by the limestone formation, their upper part comprises gray mudstone with few limestones. The Pha Kan, Doi Long and Kang Pla Formations consist mainly of platform limestones but substantial clastic sequences also occur in the Pha Kan Formation. The Hong Hoi and Wang Chin Formations are made up mainly of mudstone with subordinate sandstone, conglomerate and siltstone, and turbidites are common.

Thickness : Maximum thickness of the Lampang Group is estimated at 3,000 m and 2,000 m in the Lampang and Phrae sub-basins, respectively.

Regional extent : The Lampang Group occurs mainly in the central north of Thailand.

Contacts : In most places, it unconformably overlies the "Permo-Triassic volcanic rocks" and both unconformably and conformably overlies the Permian strata. The conformable contacts occur particularly in the Lampang sub-basin. It underlies both conformably and unconformably the "red beds" of possibly Jurassic age.

Paleontology and age : The Lampang Group commonly contains bivalves and ammonoids with few brachiopods. In the Lampang sub-basin, *Costatoria* , *Daonella* , *Posidonia* , *Paratrachyceras* , *Claraia* , *Hollandites* , and *Balatonites* are common and Scythian to middle Carnian ages are indicated. In the Phrae sub-basin, *Halobia* , *Posidonia* and *Palaeocardita* are common, and middle Carnian to early Norian ages are indicated.

Type Location : A single complete exposure of the group is nowhere exposed. The type locality for each formation is nominated under the relevant heading below.

2.5 Phra That Formation

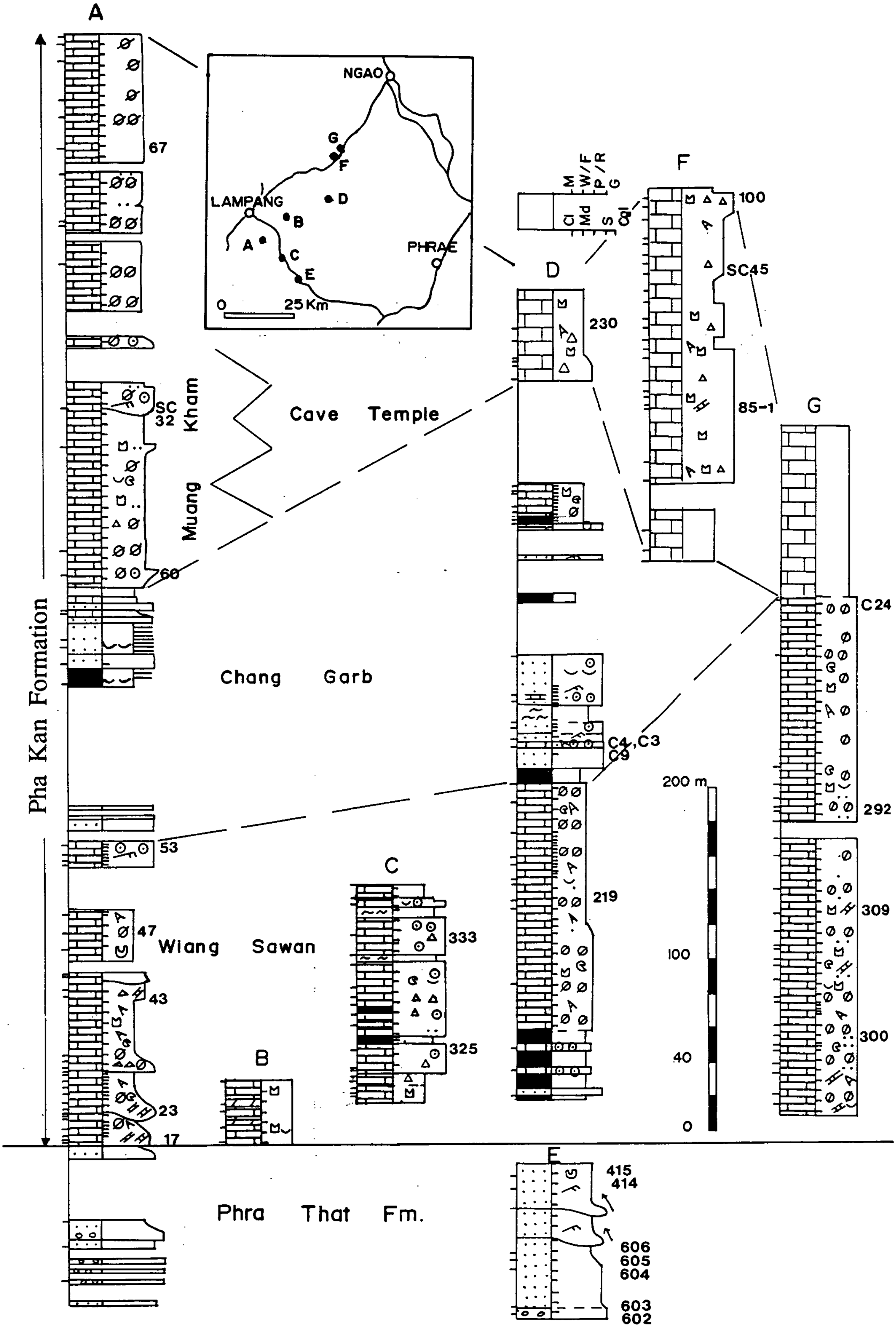
The Phra That Formation takes its name from Phra That Muang Kham temple, 12 km southeast of the town of Lampang. It is the lowermost formation in the Lampang Group and was proposed by Piyasin (1971, 1972). Lithostratigraphic columns from the measured sections are shown in Figures 2.4 A, and 2.4 E.

Synonymy : Phra That Formation (Piyasin,1971,1972; and Chonglakmani, 1972, 1981) and Phra That Muang Kham Formation (Bunopas,1981), but only in the Lampang sub-basin.

Definition : The Phra That Formation refers to the sequence between the limestone of the overlying Pha Kan Formation and the underlying Permo-Triassic volcanics, shale or limestone of Permian age. The formation occurs only in the Lampang sub-basin. The lower part of the formation consists generally of coarse- to fine-grained red siliciclastics with commonly fining-upward sequences. In the upper part of the formation its color can be gray and it is made up mainly of fine-grained gray clastics with some limestone beds. Bivalves are common. In some areas, however, the formation consists mainly of red siliciclastics. Piyasin(1972) proposed the type locality at the Phra That Muang Kham temple. An additional reference locality is proposed here at km post 31.6 to 31.9 on the Lampang-Denchai highway.

Lithology : The lower part of the formation is characterized mainly by alternating beds of feldspathic sandstone, conglomerate, siltstone and mudstone (Figs. 2.4 A, E). These are mainly red, thin to thick and nonparallel beds with normal graded beds. Fining-upward sequences and cross-stratifications are common. Mottled texture is also common. In general, fine-grained clastics increase up the sequence. Conglomerate clasts are mainly volcanics. As noted by Bunopas (1981) volcanic clasts are found only in the Mae Tha, Lampang and Ngao areas or east of these areas and have not been observed in the Chae Hom- Wang Nua area. The upper part of the formation generally consists mainly of gray mudstone and intercalated, thin- to thick-bedded gray sandstone and limestone. Fossils, particularly bivalves, often occur in this upper part, as at Huai Ngua (3.5 km north of Ban Tha Si), at the western flank of the Mae Moh Tertiary basin and at Huai Mae Sakad.

Fig. 2.4 Lithostratigraphic correlations from the measured sections of The Phra That and Pha Kan Formations. **A**) Phra That Muang Kham temple, **B**) Nopawong limestone quarry, **C**) Km 22.8 on the Lampang-Denchai highway, **D**) Doi Chang sections, **E**) Km 31.6-31.9 on the Lampang-Denchai highway, **F**) Doi Pha Khan limestone quarry, and **G**) Phra Thu Pha limestone quarry and Chao Pho Phra Thu Pha sacred place. Note lateral facies variation of the Chang Garb, Muang Kham and Cave Temple Members. The bigger limestone pattern means massive beds. Note all field sample numbers are preceded by PL, except where specified.



A
NGAO
G
F
LAMPANG
D
B
A
C
PHRAE
E
0
25 Km
67
M W/F P/R G
Cl Md S Cgl
F
100
SC45
D
230
85-1
G
Cave Temple
SC 32
Kham
Muang
60
C24
Pha Kan Formation
Chang Garb
C4, C3
C9
200 m
292
53
C
219
309
333
47
Wiang Sawan
100
43
325
300
B
40
23
17
0
E
415
414
Phra That Fm.
606
605
604
603
602

Thickness : The thickness ranges from 90 to about 650 m. The measured sections at Phra That Muang Kham temple and km post 31.6 to 31.9 on the Lampang-Denchai highway are 90 and 87 m thick, respectively (Figs. 2.4 A and 2.4 E). These two sections consist mainly of red siliciclastics. The thickness generally increases dramatically where the overlying gray clastic sequence is present, as at Ban Tha Si and Huai Mae Sakad. However, the previously reported thicknesses in some areas are worth reconsidering because of poor exposure, and most of the exposed beds dip steeply (?repeated beds). In the Ban Tha Si area the thicknesses measured by various authors are different, 200 m by Piyasin(1972), 650 m by Chonglakmani (1981), and 383.5 m by Liengsakul(1979).

Regional extent : The formation crops out in three subparallel north-south trending belts in the Lampang sub-basin (Fig. 2.1) which lies between the Khuntan Range in the west and the Doi Luang-Khun Khiat Range in the east. The eastern belt extends from east of the Mae Moh area through the western limb of the Doi Luang-Khun Khiat Range. The middle belt, possibly forming the flank of a synclinal structure plunging northeastward, extends from Ban Tha Si in the north through Phra That Muang Kham temple to Sop Prap in the south where it possibly joins the eastern belt in Sop Prap area. The western belt extends in the Chae Hom- Wang Nua area.

Contacts : The Phra That Formation is conformably overlain by the limestone of the Pha Kan Formation, as at Phra That Muang Kham temple. The lower boundary is both conformably and unconformably underlain by volcanics of possibly Permo-Triassic age, and sedimentary strata of Permian age or older. For example, it disconformably overlies the Permo-Triassic volcanics at Huai Mae Sakad (Chonglakmani,1981), unconformably overlies the Permo-Triassic volcanics at km 9+100 m on the Lampang-Denchai highway, and unconformably overlies limestone of Permian age at Ban Sa of Chae Hom District (Piyasin,1973). It conformably overlies a sequence of Permian *Leptodus* -bearing shales at Ban Tha Si (Piyasin,1973), and conformably overlies Permo-Triassic dacitic tuff at Huai Mae Moh 6 km NE of Ban Tha Si (Muangnoicharoen et al.,1980).

Paleontology and age : The age ranges from early Scythian to early Anisian. At Ban Tha Si, the limestone beds in the lower part of the formation contain *Eumorphotis multiformis* of Scythian age while mudstone in the middle part contains a *Costatoria* assemblage of early Anisian age which can be correlated southeastward to the upper part of the formation at Huai Mae Sakad east of Mae Tha District (Sivabovorn, 1967; and Chonglakmani, 1981). The conodont *Neospathodus* *pakistanensis* of latest Dienerian- earliest Smithian age is reported from interbedded limestone cropping out on the gravel road just a few meters west of the Phra Thu Pha limestone quarry (Dr. C.F. Burrett, unpublished data).

Reference locality : The sequences at the type locality, Phra That Muang Kham temple, are poorly exposed. An additional reference locality is proposed here at km 31.6 to 31.9 on the Lampang-Denchai highway (for details, see section 2.5.1).

2.5.1 *Kilometer post 31.6-31.9, the Lampang- Denchai highway section: Reference locality*

This 87 m thick sequence has its lower part is made ~~consists~~ of a thick sequence of sandstone, siltstone and conglomeratic sandstone while the upper part consists of alternating beds of sandstone, siltstone and mudstone (Fig. 2.4 E). Fining-upward sequences are common and generally commence with coarse-grained sandstone grading up to siltstone and finally maroon mudstone. Four cycles of the fining-upward sequences (up to 4 m thick each) are observed. However, in some places maroon mudstones also abruptly overlie the sandstones (Fig. 2.5 A). Sandstone is mostly feldspathic, coarse- to fine-grained, gray to light-brown, medium to thick-bedded (normally 15-40 cm but up to 100 cm) and of nonparallel bed-type that often shows lateral thinning. Cross-stratification, ripple marks and laminations are common in red fine-grained sandstone and siltstone. Channel lag deposits occur locally. Evidence of bioturbation is rare. The mudstone is medium to thick-bedded, mainly maroon and reddish-brown with greenish-gray interbeds, and gray mottlings are common. A single interbedded mudstone unit may be 5 m thick. Conglomerate, occurring at the lowermost part of the section, is both stratified and non-stratified beds reflecting waning of the transporting agent. The conglomerate clasts are normally fine-grained (0.5-2 cm) and consist mainly of red sandstone, white vein-quartz and volcanic rocks.

As the rocks of this westerly dipping succession underlie the Pha Kan Formation, they have been mapped as the Phra That Formation (Piyasin,1972). Its lower part is faulted against volcanic rocks of possibly Permo-Triassic in age. The road-section here shows a good exposure of the formation that is better than the other available sections including the type location at Phra That Muang Kham temple. Unfortunately, no fossils have been reported and the upper boundary is not seen.

Fig. 2.5 Photographs of the Phra That and Pha Kan Formations;

A) Photograph of non-parallel- bedded sandstone (s) displaying lateral thinning of beds, having sharp contacts with the overlying mudstone (m); dip angle of cleavage within the mudstone is greater than that of the bedding, indicating a normal sequence. Phra That Formation at km post 31.6-31.9 on the Lampang-Denchai highway.

B) Maroon siltstone displaying cross-beds and lag deposits (rip-up mud clasts shown by arrow); same location as Fig. 2.5 A.

C) Oncolitic packstone having thin- to medium wavy beds and good lateral continuity, grades upward to skeletal wackestone and lime-mudstone (top right); lower part of the Wiang Sawan Member at the Phra That Muang Kham temple.

D) Dasycladacean grainstone usually occurs as dense medium beds. Same location as in Figure 2.5 C.

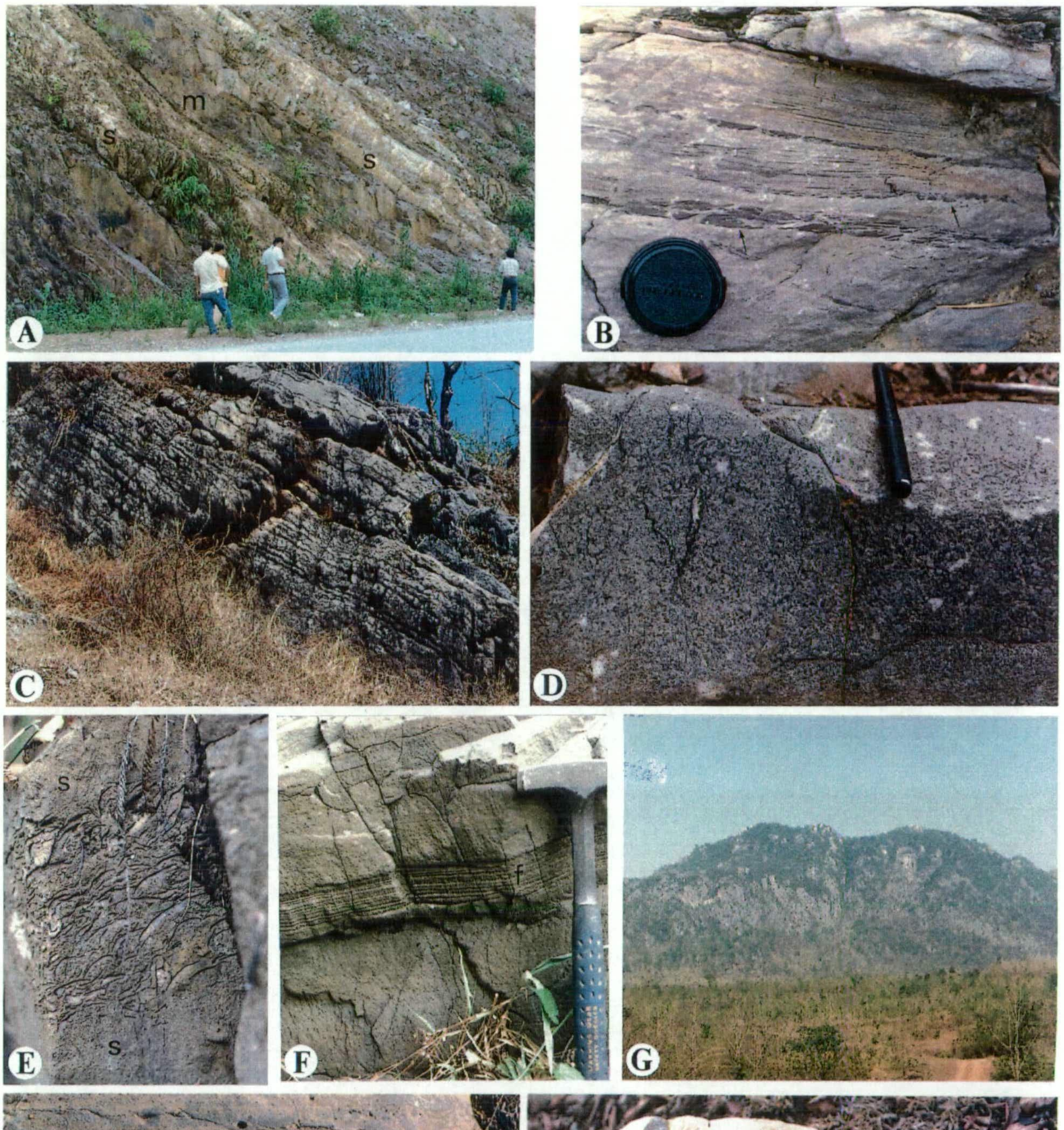
E) Coquina beds (20 cm thick) show sharp contacts with coarse- grained sandstone (s). Bivalves are mainly convex-side up, suggesting high-energy depositional conditions; Chang Garb Member at Huai Chang Garb.

F) Laminated fossiliferous beds (f) in coarse-grained sandstone; same location as Figure 2.5 E.

G) Karst topography of massively bedded limestones at Doi Chang or Mt Elephant mapped as the Cave Temple Member of the Pha Kan Formation.

H) Shallowing-upward sequence from lime mudstone (lower part of the photo) grading upward to peloidal grainstone and oolitic grainstone (middle) with cross-bedding (arrow)and sharply overlain by oncolitic packstone (ON); Muang Kham Member at Phra That Muang Kham temple.

I) Shallowing-upward sequence in oncolitic packstone indicated by size of oncoids increasing upward (to left of the photo); Muang Kham Member at Phra That Muang Kham temple.



A
m
s
s
B
C
D
E
s
s
F
f
G
H
ON
I

2.6 Pha Kan Formation

The Pha Kan Formation takes its name from Doi Pha Kan north of Ban Tha Si and was proposed by Piyasin (1972). Its distribution is now known to be more restricted than proposed by Piyasin (1972). Lithostratigraphic columns from the measured sections are shown in Figure 2.4.

Synonymy : Pha Kan Formation (which occurs only in the Lampang sub-basin) of Piyasin (1972, 1973, 1974), Chonglakmani (1972), Bunopas (1981) and Wolfart (1987); Doi Chang Formation (only in the Lampang sub-basin) of Chonglakmani (1981), and Chonglakmani and Kenvised (1987 a, b). It is possibly synonymous with the t'l unit of Baum and Hahn (1977) to the west of the Phayao area.

Definition : The Pha Kan Formation is a predominantly carbonate unit, divided into three limestone members and one clastic member. In some areas, the formation is made up almost entirely of limestone; in the other it has an intervening clastic member. The Pha Kan Formation conformably overlies the Phra That Formation and is overlain conformably by the Hong Hoi Formation. It occurs only in the Lampang sub-basin.

Lithology : The Pha Kan Formation consists of three limestone members and one intervening clastic member: Wiang Sawan, Chang Garb, Cave Temple, and Muang Kham Members. Relationship among the members is shown in Table 1.1.

Wiang Sawan Member : This takes its name from the Wiang Sawan temple in Mae Moh village. It is characterized by alternating beds of oncolitic packstone (Fig. 2.5 C) to wackestone and wackestone with minor interbedded shale. In some areas, allochems such as dasycladaceans (Fig. 2.5 D), bioclasts, ooids or intraclasts predominate. Most limestones are dark gray to gray, thin- to thick-bedded of wavy- and nonparallel-bed type but in some places wavy and parallel beds occur. Lateral facies changes are common. The upper boundary is taken as the top of the thick oolite unit exposed at Phra That Muang Kham temple or as the top of the thick oncolite unit (base of thick clastic unit) exposed at Doi Chang.

Chang Garb Member : The member takes its name from Huai Chang Garb at Doi Chang and is characterized by alternating beds of sandstone, siltstone and mudstone with minor limestone beds (Figs. 2.4 A and 2.4 D). Sandstone and siltstone are gray, laminated to thick-bedded and medium to coarse-grained. Mudstone is gray to greenish-gray with conchoidal fracture. Limestone is mainly thin- to medium bedded packstone and grainstone and consists mostly of ooids with some oncoids and peloids. Cross-stratification is common in the sandstones, siltstones and oolites, and in some instances it is represented by oriented fossils. Bivalves as well as a benthic fauna are common and are aggregated as lenticular beds within some sandstone successions (Figs. 2.5 E, F). These bivalves commonly occur convex-side up. This member may be widely distributed in the area between Phra That Muang Kham temple and Doi Chang, and shows no significant exposure in Ban Tha Si and Phra Thu Pha areas. Its upper boundary is taken as the base of the first massive limestone unit.

Cave Temple Member : This member is named after the Neramit Cave Temple east of Mae Moh. It is distinguished from the other two limestone members by its physical appearance of massive and light gray color. It consists of packstone, grainstone, wackestone and boundstone, containing mainly allochems of bioclasts such as bivalves, coral, algae and echinoderms, and intraclasts. Karst is extensively developed (Fig. 2.5 G). The Cave Temple Member is widely distributed in Doi Chang, Neramit Cave temple, Doi Wiang Ho, southward to km post 19 on the Lampang- Denchai highway, and at Ban Tha Si northward to Pha Thai Cave.

Muang Kham Member : This member takes its name from Huai Muang Kham situated on the eastern side of the Phra That Muang Kham temple. It is characterized by alternating beds of oncolitic packstone to wackestone, peloidal-skeletal packstone to grainstone, wackestone and lime mudstone (Fig. 2.4). Shallowing-upward sequences are common (Figs. 2.5 H and 2.5 I). It is gray to dark gray, having thin to thick beds of wavy and nonparallel bed type. Fossils consist of foraminifera, echinoderms, ostracods, gastropods and bivalves. Oncoids are generally large (1-3 cm in diameter) but small oncoids (<1 cm) also occur locally. Lithologically, this member is similar to the Wiang Sawan Member but can be easily distinguished by stratigraphic position that this member overlies the Chang Garb Member. In the area studied this member crops out mainly in Phra That Muang Kham temple and adjacent areas.

Thickness : The thickness ranges from 400 to 640 m. A thickness of 640 m was measured at the Phra That Muang Kham temple, 465 m at the Doi Chang section and 400 m at the Phra Thu Pha section.

Regional extent : The Pha Kan Formation occurs mainly in three narrow belts. The eastern belt of NE-SW trend is exposed from Mae Moh southward to the Mae Tha area. The middle belt crops out from the Pha Thai Cave in the north to south of the Mae Tha District. The western belt crops out in the Sop Prap, Chae Hom and Wang Nua areas (Fig. 2.1).

Contacts : The formation conformably underlies the Hong Hoi Formation and conformably overlies the Phra That Formation, as at Phra That Muang Kham temple.

Paleontology and age : Limestone of the Wiang Sawan Member at km 9.6 on Lampang- Denchai highway contains the conodont *Neospathodus pakistanensis* of the lower Triassic (uppermost Dienerian- lowermost Smithian) (Dr. C.F. Burrett, unpublished data). The fossils collected by Pitakpaivan (1955) in Mae Moh area and identified by Chonglakmani (1981) as the *Hollandites-Balatonites* zone, and *Spirigera* sp. of late Anisian age may be correlated to the Chang Garb Member. The Chang Garb mudstones at Phra That Muang Kham temple section also contain *Pteria, Pecten, Elegantia, Eumorphotis, Entolium, Costatoria* of Anisian age (identified by Dr. Chongpan Chonglakmani , pers. comm., 1990)

Reference section : The measured sections at the Phra That Muang Kham temple (see 2.6.1), Doi Chang (see 2.6.2) and the Phra Thu Pha limestone quarry (see 2.6.3) are regarded as reference sections (hypostratotypes) of the Pha Kan Formation. They are readily accessible and have good exposures through an almost complete sequence whereas other sections (Doi Pha Khan limestone quarry (see 2.6.4), and km post 22+800 m on the Lampang-Denchai highway, see 2.6.6) do not.

2.6.1 *Phra That Muang Kham temple section: Reference section*

The Pha Kan Formation at Phra That Muang Kham temple is 640 m thick and crops out along the gently sloping road to the temple. It can be subdivided into three members. In ascending order these are the Wiang Sawan, Chang Garb, and Muang Kham Members (Fig. 2.4 A). About 60 m of the lowermost part of the Wiang Sawan Member was measured from the exposure to the right front of the temple, followed by outcrops along a small creek left front of the temple and then across the railway road. Sections from the uppermost part of the Wiang Sawan Member as well as the Chang

Garb and Muang Kham Members were taken along the road to the temple. The formation conformably overlies the Phra That Formation but its upper boundary is concealed by Quaternary deposits.

Wiang Sawan Member : A 180 m thick sequence has its lower part consists mainly of alternating beds of dasycladacean grainstone, oncolitic wackestone to packstone, and skeletal packstone to wackestone and lime mudstone and minor oncolitic grainstone. Fine-grained limestones dominate in the middle part of the member. Small scale shallowing-upward sequences consisting of either oncolitic packstone grading up to dasycladacean grainstone or wackestone grading up to skeletal grainstone are common. However, the overall sequence deepens upward as shown by the abundance of dasycladacean grainstone rich in the lower part and the change to a predominance of lime mudstone rich in the upper part of the sequence (Fig. 2.4 A). Beds are thin to medium, nonparallel and wavy. Oncolitic and skeletal wackestone are closely associated with thin layers (1-2 cm thick, gray on fresh surfaces and weathering yellow or yellowish brown) of lime mudstone which partly wraps around the oncoids. Under the microscope, some of these enveloping layers are seen to be replaced by dolomite. Oncoids are spherical to elongate, normally 1-3 cm in diameter, crinkled with irregular cortices and have bioclastic nuclei except in the oncolitic grainstone where their size is mostly smaller than 1 cm. Fossils are generally diverse; blue-green algae, gastropods, bivalves, foraminifera, and echinoderms are common in coarse-grained limestone while foraminifera dominate in the wackestone and lime mudstone.

The uppermost part of the member, about 15 m thick, consists mainly of laminated to thin-bedded, commonly cross-bedded, oolitic grainstone with minor oncolite.

Chang Garb Member : A147 m thick sequence consists mainly of sandstone and mudstone with minor carbonate beds of ooids, oncoids and peloids. However, the exposure here is poor due to intense weathering. The sandstone is commonly feldspathic, partly calcareous and is gray to greenish-gray and fine- to coarse-grained. Oolitic grainstone to packstone is dark gray to gray and thin-bedded to laminated, and commonly occurs in the lower part of the member while oncolites often occur in the upper part. These suggest a gradual lithological change from the oolite-rich and oncolite-rich beds of the underlying and overlying members, respectively. Bivalves, crinoids and fossil wood occur commonly in sandy mudstone in the middle part of the sequence, and bioturbation occurs locally. These fossils are *Pteria, Pecten, Elegantia, Eumorphotis, Entolium, Costatoria* of Anisian age (identified by Dr. Chongpan Chonglakmani - pers. comm, 1990)

Muang Kham Member : This 323 m thick sequence consists mainly of alternating beds of oncolitic packstone to wackestone and lime mudstone with minor peloidal-skeletal packstone to grainstone, and oolitic grainstone (Fig. 2.4 A). Shallowing-upward sequences occur locally as shown by oncolitic wackestone grading up to oolitic grainstone, and lime mudstone grading up to oolitic grainstone (Fig. 2.5 H). Oncoids range in size up to 3 cm (mode 1-3 cm), and are irregular to subspherical in shape. However, small oncoids (<1 cm in diameter) occur locally and in at least one location a gradual change in oncoids' size from small upward to large is observed (Fig. 2.5 I). Peloids and skeletal grains occur as matrix in the oncolite, while the skeletal grains also served as nucleus for oncoid growth. Fossils consist of algae, bivalves, gastropods, foraminifera, ostracods, and echinoderms. The rocks are dark gr~~a~~ey to gr~~a~~ey and thin to medium bedded (5-15 cm but can be 50 cm thick) with wavy and non-parallel bed-type. Cross-bedding is common in oolite. Stylolites are common and weather yellow.

2.6.2 *Doi Chang section: Reference section*

This section is made up from two adjacent but separate areas. A thickness of 110 m in the lower part of the section was measured from the limestone quarry belonging to the Mae Moh Mine. The remainder commences at the western side, just a few meters below the top of a small hill west of the Doi Chang (grid reference 818272 sheet-4945-1, Ban Tha Si). The section then followed a small creek down to the eastern side and up to mountain 808 which is called Doi Chang. Doi Chang is a local name; on the topographic map it is shown as Doi Pha Chi.

Three conformable members of the Pha Kan Formation, in ascending the Wiang Sawan, Chang Garb, and Cave Temple crop out here. The lower boundary of the formation is concealed. The upper boundary is not observed but to the north of Doi Chang it is conformably overlain by the Hong Hoi Formation.

Wiang Sawan Member : A 182 m thick sequence is dominated by interbedded dark gray oncolitic wackestone to packstone and skeletal wackestone to lime mudstone with a few interbedded mudstones, sandstone and oolite in the lower part (Fig. 2.4 D). The sequence is thin- to thick-bedded with non-parallel to wavy bed type. Oncoids are 1-3 cm in diameter and have irregular cortices. The wackestone and lime mudstone increase proportionally up the sequence. Gradational contacts between wackestone and oncolite are common. Fossils are low in diversity, consisting of foraminifera and crinoid stems; some occur as lag deposits. Dolomite occurs commonly throughout the member. Intercalated sandstones are fine-grained commonly showing cross-stratification. The rocks of this member in this vicinity also crop out on the western side of Doi Pha Kap and west of Thum Chang Pheuk temple.

Chang Garb Member : This 233 m thick sequence is characterized by alternating beds of sandstone and mudstone to shale with minor limestone beds (Fig. 2.4 D). Sandstone is gray, medium to fine-grained, laminated to thin-bedded with some thick to massive beds in the middle part, and common cross-bedding. Mudstone and shale are gray to greenish-gray, and mostly calcareous with the mudstone showing conchoidal fracture. Limestone is mainly oolitic packstone, gray to dark gray, thin-bedded to laminated, and is often cross bedded but in the upper part of the sequence limestone is mainly wackestone, gray to dark gray and thin- to thick-bedded with nonparallel to wavy bed type. Ooids and oncoids occur locally in the upper part. Gradational contacts from mudstone up to oolite are observed indicating shallowing-upward sequences. Echinoderms and foraminifera are common in limestone while bivalve coquina is common in the sandstone (Fig. 2.5 E) with some being imbricated, and cross-bedded.

Ammonite samples collected by Pitakpaivan (1955) and reidentified by Chonglakmani (1981) as the species representing the *Hollandites-Balatonites* bed of late Anisian age are probably equivalent to the middle part of this member.

Cave Temple Member : At least 50 m thickness was measured from the karst outcrop at Doi Chang (Figs. 2.4 D and 2.5 G). The member consists of skeletal packstone, grainstone and wackestone. Skeletal grains consist mainly of algal debris with subordinate echinoderms and foraminifera. These rocks are light gray, massive bedded, and slightly recrystallized with hardly recognizable beds. The residues from dissolved limestone suggest that it is pure carbonate, containing white fine-grained quartz sand and algae. Southward at the Neramit Cave temple, limestone is largely massively bedded packstone to lime mudstone containing intraclasts, bioclasts (e.g. coral, algae) and oncoids.

2.6.3 *Phra Thu Pha limestone quarry section*

This 400 m thick composite section was measured from two areas; 160 m of the lower part was measured from the limestone quarry at km post 645.2 on the Phaholyothin highway, while the upper part was estimated from the outcrops along the highway between the quarry and the Chao Po Phra Thu Pha sacred place. The section consists of two members, the Wiang Sawan and the conformably overlying Cave Temple (Fig. 2.4 G).

The Wiang Sawan Member, about 300 m thick, consists predominantly of dark gray oncolitic packstone to wackestone, and peloidal and skeletal packstone to grainstone, with minor wackestone to lime mudstone. Shallowing-upward sequences are common. Beds are medium to thick(15-50 cm) with minor thin beds of parallel and wavy type. Oncoids are common to abundant throughout the sequence, sometimes representing 80% of the rock. Oncoids are 1-3 cm in diameter, round with irregular cortices. They consist of both types, with and without nuclei. Peloids, dasycladacean algae and shells serve as nuclei for oncoid growth. The matrices of oncolites are usually peloids and bioclasts. Fossils consist mainly of foraminifera, echinoderms, gastropods, bivalves, and dasyclads.

The Cave Temple Member is about 100 m thick lying conformably the Wiang Sawan Member (shown at km 647.5 along the Phaholyothin highway). It consists mainly of massively bedded, gray to light gray limestone.

2.6.4 *Doi Pha Khan limestone quarry section*

This section is situated at the limestone quarry at the northern end of Doi Pha Khan, 43 km north of the town of Lampang. It is regarded here as the Cave Temple Member.

This 216 m thick sequence consists of skeletal and intraclastic grainstone to packstone, wackestone and lime mudstone (Fig. 2.4 F). Skeletal grains consist mainly of algal debris with subordinate echinoderms, bivalves and gastropods. These rocks are massively bedded, light gray and slightly recrystallized. Bedding is difficult to discern. Steeply dipping beds at the quarry are suggested by the beds of the adjacent formations, and this is confirmed by a microscopic study. Looking carefully, an association of sparry calcite and intraclast can be observed, and some alignments of allochems indicate influence of currents.

2.6.5 *Nopawong limestone quarry section*

This section is considered as Wiang Sawan Member. It is situated at the limestone quarry at a small hill, 3 km north of Ban Pha Lad, on the western side of the road to the Mae Moh Mine. Both lower and upper boundaries are covered by Quaternary basalt. However, at km post 9.6 on the Lampang- Denchai highway or 4.5 km southwest of this section, the limestone contains conodonts *Neospathodus pakistanensis* , of latest Dienerian to earliest Smithian age (Dr. C.F. Burrett, unpublished data) and is conformably underlain by the Phra That Formation that unconformably overlies the "Permo-Triassic volcanic rock".

This 40 m thick sequence is represented by steeply northwestward dipping beds of limestone and minor shale (Fig. 2.4 B). Limestone, consisting mainly of wackestone and lime mudstone, is dark gray and thin- to medium bedded (10-20 cm thick, with partial thick beds), with wavy and non-parallel beds. Shale is thin-bedded (1-3 cm thick) and gray in color and has a well developed cleavage. Fossils are scarce and consist mainly of echinoderms and foraminifera. Evidence of bioturbation is rare.

2.6.6 *Kilometer post 22+800 m on the Lampang-Denchai highway section.*

This section is an isolated road-cut outcrop of nearly vertical westward-dipping beds. It is considered here as part of the Wiang Sawan Member based on its lithology and stratigraphy. Neither upper nor lower boundary is observed. Stratigraphically, it forms as an eastern limb of a syncline and is overlain to the west by the Chang Garb and Cave Temple Members.

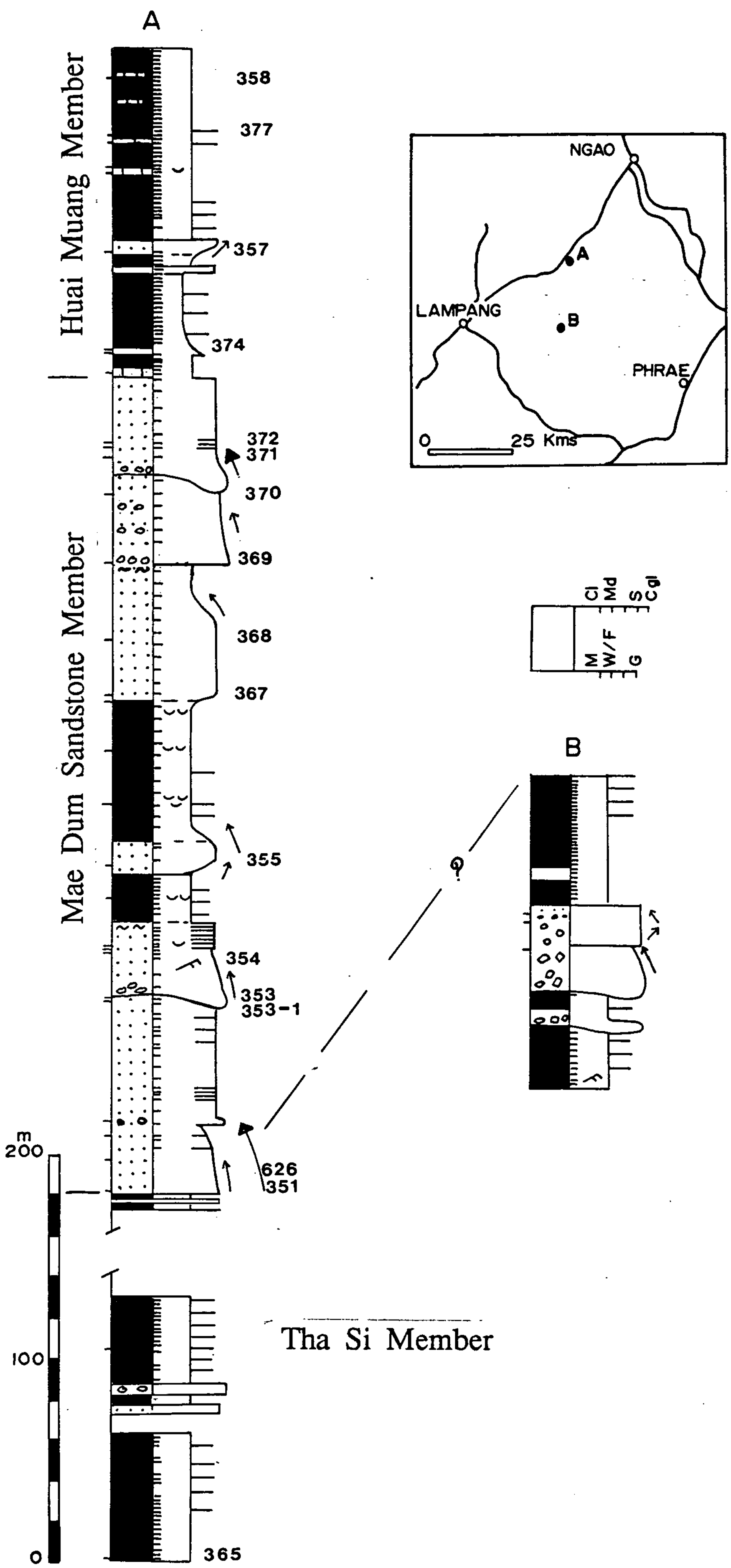
A sequence of 125 m thick is represented mainly by alternating beds of grainstone, packstone and calcareous shale with minor sandstone (Fig. 2.4 C). Allochems are mainly ooids, intraclasts, and skeletal grains. Shale is greenish-gray, weathering to yellowish-brown. Limestone is dark gray, thin- to medium (5-15 cm) and non-parallel to wavy bedded, partly laminated and partly massively bedded (up to 3 m thick). The contacts between shale and limestone are both sharp and transitional. Fossils consist mainly of gastropods, bivalves, crinoids, foraminifera, and algae. Shallowing-upward sequences are observed and show grading from wackestone up to grainstone with each cycle being about 50 cm thick or more.

2.7 Hong Hoi Formation

With regard to Pitakpaivan (1955) who proposed the name " Hong Hoi Shale and Sandstone" to represent sandstone and grayish-green shale containing ammonoids and bivalves in the Mae Moh area, Piyasin (1972) named it the Hong Hoi Formation. However, it is now known that its distribution is more restricted, as is its fossil content and age (see discussion in sections 2.1 and 2.2). Lithostratigraphic columns from the measured sections are shown in Figure 2.6.

Synonymy : Hong Hoi Formation (only in the Lampang sub-basin) of Piyasin (1972,1973,1975), Chonglakmani (1972,1981,1983), Liengsakul (1979) and Bunopas (1981); Hong Hoi Shale and Sandstone (Pitakpaivan, 1955; and Keereevat and Suensilpong, 1965).

Fig. 2.6 Lithostratigraphic column of the Hong Hoi Formation showing subdivided members, the Tha Si, Mae Dum Sandstone, and Huai Muang; **A)** at Huai Mae Dum-Huai Muang of Ban Tha Si, **B)** at km 4.2 on the canal road of the Mae Chang Dam. Note all field sample numbers are preceded by PL, except where specified.



A
Huai Muang Member
Mae Dum Sandstone Member
Tha Si Member
358
377
357
374
372
371
370
369
368
367
355
354
353
353-1
626
351
365
m
200
100
0
NGAO
LAMPANG
PHRAE
A
B
0
25 Kms
Cl
Md
S
Cgl
M
W/F
G
B
?

Definition : The Hong Hoi Formation is that sequence generally lying between the limestones of the overlying Doi Long Formation and the underlying Pha Kan Formation. However, in some places it may be conformably overlain by the Pha Daeng Formation or conformably underlain by Permian strata. It consists mainly of fine-grained turbidites, i.e., gray to greenish-gray mudstone with subordinate sandstone, siltstone and minor limestone and conglomerate. Ammonoids *Paratrachyceras* and bivalves *Posidonia* and *Daonella* are common in mudstone. The formation occurs in the Lampang sub-basin and consists of three members: the Tha Si, Mae Dum Sandstone and Huai Muang. The type locality of the formation is situated along the Huai Mae Dum and the Huai Muang.

Lithology : There are three members of the Hong Hoi Formation.

Tha Si Member : Takes its name from Ban Tha Si and is characterized by mudstone and minor intercalated sandstone, conglomerate and limestone. Mudstone is gray to greenish-gray and laminated or structureless, and commonly displays conchoidal fractures. The lamination was formed by interbedding of mudstone and laminated siltstone. Sandstone is thin- to medium bedded, fine- to coarse-grained and often normally graded, and frequently contains feldspar and fossil wood fragments. Gravity flow sediments are present. This member is exposed along the Lampang-Ngao (Phaholyothin) highway. Its upper boundary is taken as the base of a thick sandstone bed.

Mae Dum Sandstone Member : This takes its name from Huai Mae Dum where good exposure occurs. It is characterized by sandstones with alternating conglomerates and mudstones (Fig. 2.6). Thinning-and fining-upward sequences of sandstone beds occur in places, as do even and parallel interbedded sandstone and mudstone (Fig. 2.9 A). Sandstones are gray, thin- to massively bedded and medium to coarse-grained; they often contain feldspar and fossil wood fragments, commonly display normally graded beds (Fig. 2.9 B) and usually show sharp contacts with the underlying mudstones. Flute structures are rare to absent. Lamination, ripple marks, and cross-stratification occur locally in sandstone and siltstone. There are also rare channel structures. Conglomerates are both clast-supported and matrix-supported and clasts are made up mainly of volcanics and in some cases, limestones. Mudstones are generally thin units, but can be thick and are interbedded with laminated to thin-bedded sandstone to siltstone, and fossils of the ammonoids *Paratrachyceras* and the bivalves *Posidonia* sp. and *Daonella* sp. are usually common. Upper boundary of the member is taken as the base of the first overlying limestone bed.

Huai Muang Member : Its name is borrowed from Huai Muang where good rock exposures occur. It is characterized by mainly gray to greenish-gray mudstone and shale with intercalation of limestone as beds or nodules and laminated siltstone (Fig. 2.9 C). The proportion of limestone, commonly laminated, increases up the sequence. In thin section, limestones commonly contain thin-shelled fossils. There are also some papery clayshale, sandstone and pebbly sandstone beds. The existence of this member may bear a close relationship with an occurrence of the Doi Long Formation.

Thickness : A 700 m thick sequence was measured in the Huai Mae Dum-Huai Muang section where the lower boundary of the formation is not seen. However, the measured thickness differs markedly from previous estimates, i.e., 1200 m by Piyasin (1972), and 1900 m by Chonglakmani (1981).

Regional extent : This member crops out mainly in two areas in the Lampang sub-basin. These are the Sop Prap-Chae Hom-Wang Nua and the Mae Tha-Mae Moh-west of Ngao and Phayao areas, and it possibly extends to the Chiangrai region.

Contacts : Generally, it conformably underlies the Doi Long Formation as at Huai Muang and Huai Tad (Keereevat and Suensilpong,1965). However, where the Doi Long Formation is not developed, it is overlain by the Pha Daeng Formation as on the road to Mon Talai Nok temple, 3.5 km SE of Ngao. It conformably overlies the Pha Kan Formation at Ban Tha Si (Liengsakul, 1979) and to the north of Doi Chang. However, where the Pha Kan Formation is not developed, it conformably overlies Permian shale and sandstone as at Ban Huat west of Ngao District, Permian tuffaceous shale and sandstone at Huai Or Dong west of Mae Wang Dam and Permian limestone at Huai Mae Bon west of Sop Parp and at Huai Mae Mae of Chae Hom District (Chonglakmani,1981). It also unconformably overlies Permian strata at Huai Mae Tha southeast of Chae Hom (Piyasin,1972; Chonglakmani,1981; Bunopas,1981).

Paleontology and age : The oldest rocks of the Hong Hoi Formation seem to occur in the central part of the elongated basin such as west of Ngao and Sop Parp areas, and the sequence becomes younger towards the flank (Fig. 2.1-the overlay). The formation ranges from lowermost Triassic to lower upper Triassic. According to Chonglakmani (1981), the *Claraia-Ophiceras* fauna, such as *Claraia stachei* , *Claraia concentrica* , of late Griesbachian age occur in Ban Bon west of Sop Parp, in Ban Huat west of Ngao, and Huai Or Dong west of Mae Wang Dam. The *Daonella indica* zone of late Ladinian age occurs in Ban Pang La, and Huai Khok Chang of Ko Kha

District. Lower Carnian fauna dominated by the ammonoids *Paratrachyceras* and bivalves *Daonella* and *Posidonia* occurs in the Ban Tha Si, Mae Moh and Chae Hom areas (Chonglakmani, 1981). *Sirenites (Sirenites) senticosus* , a typical fossil of early Carnian age, is reported from northwest of Phayao Province (Jordan,1973). At Chae Hom District, Baum et al. (1970) reported the upper Scythian conodonts, *Hadrodontina anceps* and *Pachycladina symmetrica* , in the basal conglomerate of the Hong Hoi Formation.

Type locality : A good exposure of the Hong Hoi Formation crops out from Huai Mae Dum to Huai Muang NE of Ban Tha Si which is regarded as the type locality.

2.7.1 *Huai Mae Dum -Huai Muang section: Type section*

A good exposure of the Hong Hoi Formation crops out along Huai Mae Dum to Huai Muang, 45 km north of the town of Lampang. This traverse section is the same as that of Keereevat and Suensilpong (1965), and Piyasin (1972). The lithostratigraphic column is shown in Figure 2.6.

Tha Si Member : A thickness of at least 140 m was measured along a small creek about 500 m east of kilometer post 647 on the Phaholyothin highway or close to the northern side of the "Phra Thu Pha" army camp (grid reference 862442 sheet 4945-1, Ban Tha Si), then downstream to Huai Mae Dum. This steeply westward-dipping sequence, probably conformably overlies the Cave Temple Member that also crops out along the highway, consists mainly of mudstone and shale with minor sandstone beds. Mudstone and shale are gray to greenish-gray with conchoidal fracture and laminations in places. The laminations are formed by interbeds of mudstone and siltstone. Sandstones are feldspathic, gray, thin to medium bedded, and commonly contain fossil wood fragments. There are also some conglomerate beds with rounded clasts consisting mainly of sandstone, quartzite, limestone and black siliceous shale.

Mae Dum Sandstone Member : This member is exposed along Huai Mae Dum and Huai Muang (between grid references 863428 and 868423, sheet 4945-1), on the southern side of the army camp.

This 400 m thick sequence is dominated by sandstone with subordinate interbedded mudstone in the middle part of the sequence (Fig. 2.6). This southeasterly dipping sequence commences as a massive bed (about 2 m thick) of coarse-grained sandstone followed by a thick sequence of alternating beds of thin- to thick-bedded (5-60 cm thick), partly laminated, medium to coarse-grained, gray sandstone, and thinly bedded (1-10 cm), gray mudstone. There are also a few conglomerate beds. Fossil wood fragments with their long sides parallel to the bedding plane as well as feldspar are common in sandstone. Normally graded beds and lamination (Fig 2.9 B) are common, and cross-stratification, ripple marks and scour marks occur locally. Reverse-graded beds occasionally occur especially in thick-bedded and coarse-grained rocks. Fining-upward sequences of fine-grained conglomerate with low amplitude sole marks grading upward to laminated sandstone locally occur.

Toward the top of the lower part, a 15 m thickness consists of couplet beds (Fig. 2.9 A) of fine- to medium grained, gray sandstone and mudstone which are exposed for more than 3 km along Huai Mae Dum. The couplets are thin- to medium bedded (generally less than 10 cm thick) with good lateral continuity of beds containing some lamination, flame structures and rare current ripples. Generally, mudstone has a sharp contact with the overlying sandstone bed. Tiny *Posidonia* of early Carnian age was collected from this part of the succession (identified by C. Chonglakmani, 1990). A similar sequence like the lower part also occurs in the upper part of the sequence along Huai Muang.

The middle part of the sequence consists mainly of conchoidally fracturing, gray mudstone with minor sandstone. The gray mudstone contains several beds of *Paratrachyceras, Lobites, Posidonia* and *Daonella* which is probably belong to the *Paratrachyceras* zone, of early Carnian age, of Chonglakmani (1981).

Huai Muang Member : A 160 m thick sequence is exposed along Huai Muang, from where its name is derived, to Doi Pha Bong. It consists mostly of gray to greenish-gray mudstone and intercalated limestone, and minor papery clayshale, sandstone and pebbly sandstone (Figs. 2.6 and 2.9 C). Mudstone is mostly calcareous, of moderately developed fissility (mudshale), has a conchoidal fracture and is partly interbedded with laminated siltstone. Limestone, mainly lime mudstone, increases in proportion up the sequence and is dark gray, thin-bedded to nodular, partly laminated and cross-laminated. Gradational contacts between mudstone and limestone are common. Sandstone is gray, medium to coarse-grained, medium to thick-bedded, and contains partly calcareous and reverse- to normally graded beds. Sandstone occurs less frequently towards the top of the sequence. Fossils are rare.

2.8 Doi Long Formation

As mentioned earlier, Piyasin (1972) mapped the rocks at Doi Huai Long as Doi Chang Formation while the rocks at Doi Chang were mapped as Pha Kan Formation. Chonglakmani (1981) following ~~according~~ to Piyasin (1971), ~~therefore~~, reintroduced the name Doi Long Formation for the limestone unit lying between the Hong Hoi and Pha Daeng Formations. It takes its name from Doi Huai Long, situated in a NE-SW trend, 3 km east of Ban Tha Si or 40 km NE of the town of Lampang.

Five sections along the western flank of the "Tha Si syncline", about 30 km long, have been measured (Fig. 2.7). The sections are normal to the depositional strike of the strata as well as to the mountain trend, commencing from bottom to top of the strata approximately in a NW toward SE direction. Section A is the southern part of a small hill 1.5 km east of Ban Pang La, grid reference 916504, sheet 4946-2-Ban Pong, scale 1:50,000. Sections B to E are from map sheet 4945-1-Ban Tha Si, scale 1:50,000. Section B is from the northern cliff of Doi Pha Bong (868419). Section C is situated along the walking-track across the crest of the mountain at grid reference 851392. Section D is on the cliff of Doi Huai Long, east of Ban Tha Si, grid references 822372 to 823370 and the top part of the section is at 828371. Section E starts on the cliff of Doi Nok at grid reference 842306. Lithostratigraphic columns from the measured sections are shown in Figure 2.7.

Synonymy : The Doi Long Formation is synonymous with the Doi Chang Formation of Piyasin (1972,1973,1975), Chonglakmani (1972), Bunopas (1981); and the Doi Long Formation of Chonglakmani (1981), Chonglakmani and Kenvised (1987 a,b) but excluding limestone-conglomerate.

Definition : The Doi Long is a carbonate formation, occurring between the Hong Hoi and Pha Daeng Formations. It consists mainly of light gray, massively bedded, often dolomitic limestone. Lithologically, it is made up mainly of algae and peloids but in some places bioclasts are predominant and a patch reef occurs locally. The type locality is situated at Doi Huai Long.

Lithology : The Doi Long Formation is characterized by packstone to grainstone of peloids, oncoids and algal debris with minor bioclasts, oolite and stromatolite beds or lenses (Fig. 2.7). The unit is light-gray with scattered yellowish-brown patches and mostly massive with no bedding visible, except at Doi Nok where bedding is present as non-parallel and wavy beds. Fossils are scarce but may be abundant locally, especially in the upper part of the formation. Bioturbation is not common. Algal boundstone, peloidal algal packstone and skeletal packstone dominate in all measured sections, whereas oolitic grainstone and stromatolite occur at Doi Nok and Doi Huai Long, respectively. Isolated corals (0.5 cm in diameter and 3 cm long, lying in NW-SE direction) are also scattered in the lower part of the Doi Huai Long and Doi Pha Bong sections and mostly have been replaced by sparry calcite. Late diagenetic dolomites weathering light brown are common. The upper part of the formation is generally interbedded with red to pink wackestone as at the Doi Huai Long and Doi Pha Bong sections. It is suggested that in the absence of fossil and stratigraphic control, the Doi Long Formation may be distinguished from the Cave Temple Member, on the basis of their lithology in which the former is dominated by peloids, type C oncoids (see Chapter 3) and algal debris.

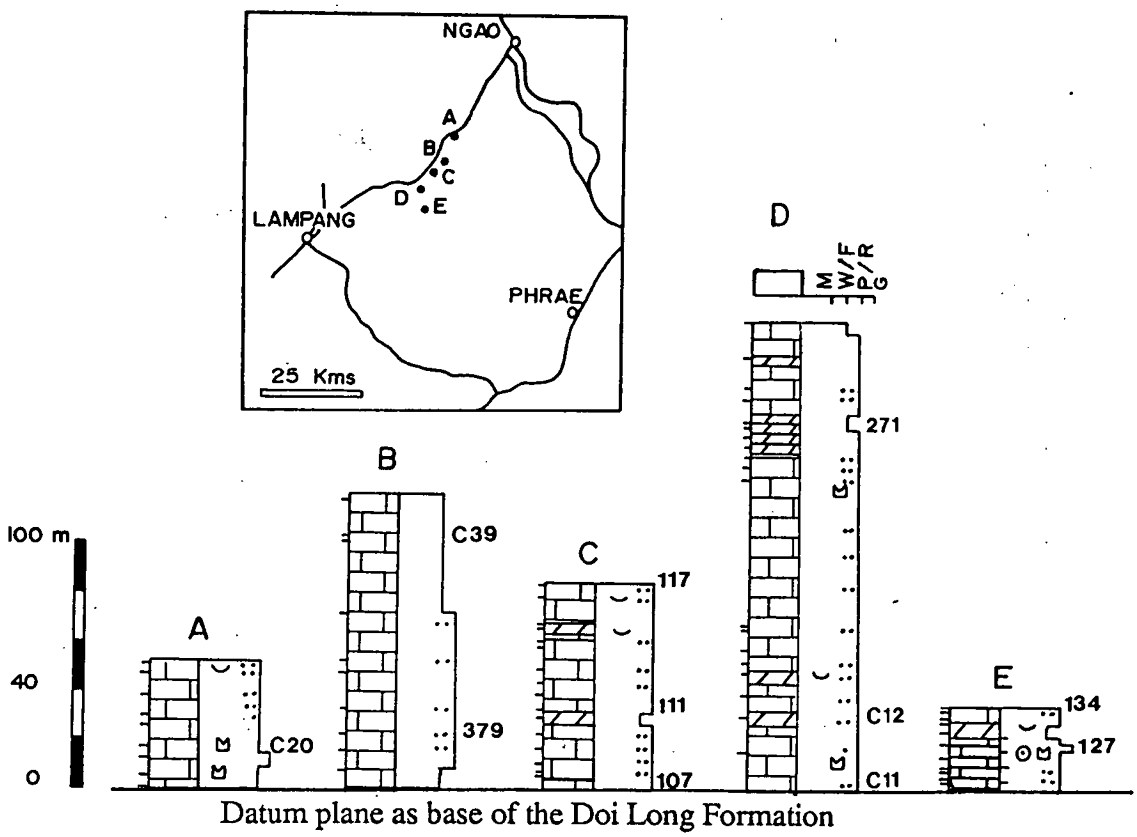


Fig. 2.7 Lithostratigraphic correlations from the measured sections of the Doi Long Formation. A) Ban Pang La, B) Doi Pha Bong, C) Doi Long, D) Doi Huai Long, and E) Doi Nok. Note all field sample numb··· are preceded by PL, except where specified.

Thickness : The formation may be lensoidal. It is thickest (230 m) at the Doi Huai Long area, on the western limb of the "Tha Si Syncline".

Regional extent : This formation is distributed in a narrow zone, mainly in the western limb of the "Tha Si syncline" and sporadically crops out on low-lying plain at the eastern limb of the syncline. A karst topography is developed.

Contacts : The formation is both conformably and unconformably overlain by the Pha Daeng Formation. The conformable contact is shown by the northwesterly dipping of light gray and red limestone beds at Huai Kuan. The unconformable contact is evidenced by the local occurrence of limestone conglomerate, for example at Doi Pha Bong. Its lower boundary conformably overlies the Hong Hoi Formation with transitional contact as shown in the Huai Muang and Huai Tad areas (Keereevat and Suensilpong, 1965).

Paleontology and age : The middle Carnian *Trigonodus costatus* collected from reddish gray argillaceous limestone clast in the Ban Tha Si area (Chonglakmani, 1981) is probably equivalent to the upper part of this formation.

Type locality : The Doi Huai Long east of Ban Tha Si is the type locality proposed by Chonglakmani (1981). The exposures at the Doi Pha Bong and at the Doi Nok are also good and are proposed as reference localities (for details see 2.8.1).

2.9 Pha Daeng Formation

The rocks of this formation in the Huai Ting Tue-Doi Pha Bong area were mapped by Keereevat and Suensilpong (1965) as "Pha Bong limestone conglomerate, Pha Daeng sandstone and conglomerate, and Doi Gum Phra shale". Piyasin (1972,1975) named the Pha Daeng Formation to encompass these rocks but excluded the Pha Bong limestone conglomerate which he considered to be part of the Doi Long Formation. However, the occurrence of the limestone conglomerates which occur in two stratigraphic levels and which is separated by more than 100 m of red sandstone (Fig. 2.8 A), and the transported origin of grains all favor the Pha Daeng Formation rather than the Doi Long Formation. Lithostratigraphic columns from the measured sections are shown in Figures 2.8 and 2.10.

Synonymy : The Pha Daeng Formation (Piyasin, 1972, 1973, 1975; Chonglakmani, 1972, 1981; Liengsakul, 1979; Bunopas, 1981); Thung Po Formation

(Chonglakmani and Tiyapun, 1985); Unit ms1, h and h2's, particularly in Ngao area, of Baum and Hahn (1977); Phra That Formation (only in the Phrae sub-basin) of Piyasin (1972, 1973, 1974, 1975, 1980), Chonglakmani (1972, 1981), and Bunopas (1981); lower part of the Mae Thang Formation (Chonglakmani and Tiyapun, 1985).

Definition : The Pha Daeng Formation is that sequence, predominantly of siliciclastic rocks, which normally overlies the Doi Long Formation but in some places conformably overlies the Hong Hoi Formation or unconformably overlies volcanics that may be of Permo-Triassic age. It conformably underlies the Kang Pla Formation and in some places the Wang Chin Formation. It consists mainly of sandstone, siltstone, mudstone and conglomerate. Red is the predominant color in this formation but it may consist of gray to grayish-green beds especially in the upper part of the formation. Fining-upward sequences are characteristic, and cross-bedding, ripple marks and channel structures occur locally. The type locality is situated at the Doi Pha Daeng-Huai Ting Tue.

Lithology : It is characterized by beds of red to maroon conglomerate, sandstone, siltstone and mudstone with subordinate limestone conglomerate and gray sandstone. Fining-upward sequences are characteristic. In some places, its upper part consists of gray mudstone with minor gray sandstones and limestones; fossils such as bivalves, and ammonoids may be common. Rare coal beds also occur.

The conglomerate, often lying in the lower part of the depositional cycle, is both stratified and unstratified and contains mainly volcanics, vein-quartz and red sandstone clasts. In some places, red and light gray limestone clasts are predominant and the term limestone conglomerate is applied. Sandstone is mainly feldspathic, red to brownish red and grayish-green, fine- to coarse-grained and medium to thick-bedded with wavy to parallel bedding. Small scale cross-beddings and ripple marks are common in siltstones and fine-grained sandstones. Channel structures and bioturbation occur locally. Mud cracks are a rare occurrence.

Thickness : The formation's thickness ranges from 200 to 700 m and possibly, in places, up to 1000 m thick. It appears to be thicker in the Lampang sub-basin than in the Phrae sub-basin. At the type locality at Doi Pha Daeng-Huai Ting Tue the formation is 700 m thick. This thickness is comparable with estimates of 500 m (Piyasin,1972), 600 m (Chonglakmani,1981), and 500-600 m (Bunopas,1981). At km 35+950 m to 36+295 m and at km 45+020 m to 45.4 on the Rong Kwang-Ngao highway, the thicknesses are 123 m and 206 m , respectively. Toward the south, the thicknesses of 500 m at Ban Kaeng Luang of Long District and 250 m at Ban Mae Saliam Wan of Thoen District were reported by Chonglakmani (1981).

Regional extent : Most lithofacies occur in the "Tha Si Syncline" area and distal facies extend northward to the Ngao District. Proximal facies are also exposed in the northeast of Long District. The coarse-grained facies are more common in the south (Tha Si and Long areas) than in the north (Ngao and Song areas).

Contacts : The Pha Daeng Formation conformably underlies the Kang Pla Formation. It conformably overlies the Doi Long Formation at Huai Kuan and the Hong Hoi Formation at the road to Mon Tha Lai Nok temple. It also unconformably overlies volcanics of possibly Permo-Triassic age at km 44.9 on the Rong Kwang-Ngao highway and, in a few places, the Doi Long Formation. Its lower boundary is located at the base of either the limestone conglomerate or siliciclastics.

Paleontology and age : Only middle Carnian fossils have been reported for the Pha Daeng Formation from both the Lampang and Phrae sub-basins. In the Lampang sub-basin, its lower boundary is situated just a few meters above the middle Carnian *Trigonodus costatus* collected from reddish-gray argillaceous limestone (Chonglakmani,1981). In the Phrae sub-basin, a lower middle Carnian assemblage including *Halobia styriaca* , *Halobia cassiana*, *Palaeocardita singularis* and *Cassianella tenuistria* of the *Halobia styriaca* Zone is reported from the upper part of the formation at km 45+350 m along the Rong Kwang-Ngao highway and *Halobia comata* is reported from the Doi Pha Lak Mun and at Ban Kaeng Luang (Chonglakmani,1981).

Type section : Piyasin (1972) proposed Doi Pha Daeng as the type locality of the Pha Daeng Formation but few details of the stratigraphy were described. The type section can be specified more closely as the Doi Pha Daeng-Huai Ting Tue (for details see 2.9.1). An additional reference locality is situated along km 50.5 to 61 and km 45+020 m to 45.4 on the Rong Kwang-Ngao highway. Good exposures are also found at Huai Or Dong, Huai Nam Lon (within the "Tha Si Syncline"), Huai Mae Teep Noi and Huai Pha Bong (east of Ban Paen).

Fig. 2.8 Lithostratigraphic correlations from the measured sections of the Pha Daeng Formation: **A**) Huai Ting Tue, **B**) Huai Or Dong -Huai Nam Lon, **C**) On the Song-Ngao road, 1 km south of Ban Thung Po, **D**) km post 50.500 m to -51+520 m on Rong Kwang-Ngao highway, and **E**) Huai Pha Bong. Note all field sample numbers are preceded by PL, except where specified.

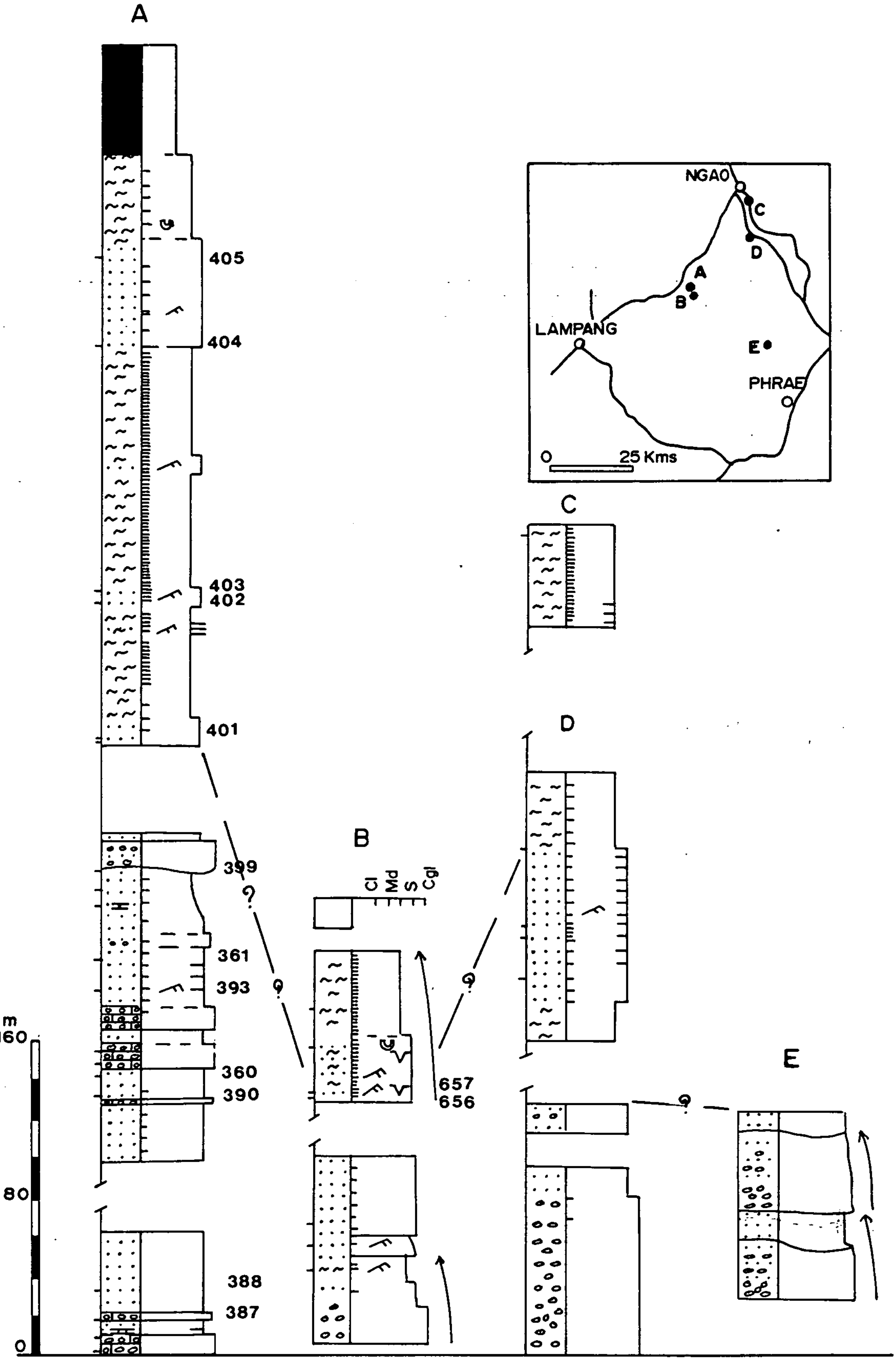

A
405
404
403
402
401
399
361
393
360
390
388
387
m
160
80
0
B
Cl
Md
S
Cgl
657
656
C
D
E
NGAO
LAMPANG
PHRAE
A
B
C
D
E
0
25 Kms

Fig. 2.9 Photographs of the Hong Hoi and Pha Daeng Formations.

A) Interbedding of sandstone (lighter-colored beds) and mudstone (darker beds). Note that they display couplet-bedded, normally graded beds which are parallel and continuous(top towards upper left); Mae Dum Sandstone Member at Huai Mae Dum NE of Ban Tha Si.

B) Coarse-grained sandstone with a normally graded bed or Bouma Ta grades up to laminated sandstone of Bouma Tb(indicated by pen), and is overlain by rippled sandstone(off the photo); Mae Dum Sandstone Member at Huai Mae Dum NE of Ban Tha Si.

C) Intercalation of limestone beds(at hammer) within the mudstone sequence is characteristic of the Huai Muang Member. Limestones are made up mainly of lime mudstone and wackestone, at Huai Muang NE of Ban Tha Si.

D) Clasts of the Pha Bong limestone conglomerate consist mainly of limestones of red and light gray colors while the matrix is composed of limestone and sandstone. Lithologies of the clasts are similar to the underlying Doi Long Formation; lower part of the Pha Daeng Formation at Doi Pha Bong NE of Ban Tha Si. Top to the left of the photograph.

E) Normally graded bed whose clasts consist mainly of red sandstone and vein-quartz; conglomerate unit of the Pha Daeng Formation at Huai Ting Tue area.

F) Interbedding of thin, parallel beds of maroon mudstone and sandstone(lighter color) displaying good lateral continuity, small scale cross-stratification and lamination. Mudstone to sandstone ratio is about 3:1 ; Pha Daeng Formation at km post 57+400 m on the Rong Kwang-Ngao highway.

G) Cracks in interbedded grayish-green and maroon mudstones, filled by grayish-green mudstone (arrow). These are probably due to dewatering processes; km post 44+552 on Rong Kwang-Ngao highway.

H) Limestone concretions (arrow)in gray mudstone sequence, partly containing benthic bivalves, lie parallel to the bedding; upper part of the Pha Daeng Formation at km 45.4 along the Rong Kwang-Ngao highway.

I) Fine-grained sandstone and siltstone of the Pha Daeng Formation commonly display small-scale cross-bedding and fining-upward sequences with a sharp-based bed; km post 36+170 m on Rong Kwang-Ngao highway.


A
B
C
D
E
F
G
H
I

2.9.1 *Doi Pha Daeng-Huai Ting Tue section: Type section*

This section commences at the base of the first limestone conglomerate cropping out on SW of the Doi Pha Daeng hillside (grid reference 872420 sheet 4945-1, Ban Tha Si). Two stratigraphic sequences of the Pha Bong limestone conglomerate are exposed on this hillside; the measured section then follows downstream along the Huai Ting Tue(grid reference 874417 to 879406 sheet 4945-1, Ban Tha Si). The remainder of the unit except the Gum Pra mudstone is exposed along this creek. The Gum Pra mudstone crops out on top of the " Tha Si Syncline" and is named after the mountain situated at grid reference 870372 of the same map sheet, Doi Gum Pra.

This 700 m thick sequence is subdivided informally into 6 units in ascending order: Pha Bong limestone conglomerate, red sandstone, conglomerate, laminated siltstone-mudstone, gray sandstone, and Gum Phra mudstone units.

Pha Bong limestone conglomerate : The limestone conglomerate unit unconformably overlies the Doi Long Formation and occurs in two stratigraphic intervals, 22 m and 34 m thick which are separated by more than 100 m of red sandstone (Fig. 2.8 A). Each interval of limestone conglomerate features intercalated red sandstone and minor bedded limestone. In the lower part of the unit, limestone conglomerate is of unstratified type, poorly sorted, and consists mainly of light gray and red limestone clasts with a calcareous cement (Fig. 2.9 D). Sandstone clast and matrix are rare in the lower part. Stratified limestone conglomerate occurs higher in the sequence. Clasts and matrices of siliciclastics also increase up the sequence. Clasts are mostly 3-10 cm in size but reach 30 cm and most are well rounded. The scarcity of siliciclastic sediments in the lower part of the sequence indicates deposition distal to terrestrial sources. Contact between the conglomerate and sandstone is both sharp and graded.

Red sandstone unit : The red sandstone unit is estimated to be at least 100 m thick and is characterized by mainly medium to thick wavy-bedded, fine- to coarse-grained red sandstone interbedded with thinner beds of siltstone, conglomerate and mudstone. It is closely associated with the limestone conglomerate and the conglomerate units. Fining-upward sequences are common but cross-stratification is rare.

Conglomerate unit : This unit is made up of interbedding of clast-supported red stratified conglomerate and sandstone with common normally graded beds and cross-stratification. Clasts, normally 1-3 cm in size, consist mainly of vein-quartz and red sandstone (Fig. 2.9 E). Thickness is estimated to be more than 20 m.

Laminated siltstone-mudstone unit : This unit is about 250 m thick and consists mainly of siltstone with intercalated mudstone and minor sandstone. These are commonly laminated and exhibit small-scale cross-stratification and fining-upward sequences. Lamination is represented by laminae of red siltstone and lighter colored, fine-grained sandstone. Cross-stratification shows a wide angle of paleocurrent direction between NE and NW. Maroon mudstone, commonly gray-mottled, dominates in the upper part.

Gray sandstone unit : This unit, 50 m thick, is characterized by medium to thick, wavy and non-parallel bedded, medium grained, gray sandstone containing black minerals and partial cross-beddings. It is closely associated with laminated red siltstone and some conglomerate beds.

Gum Pra mudstone : The unit's name comes from Doi Gum Pra. It is characterized by interbedded maroon and grayish-green mudstones and minor sandstones. Thickness is estimated to be more than 100 m.

2.9.2 *Kilometer post 50+500 m to 50+850 m, and 51+365 m to 51+520 m, the Rong Kwang-Ngao highway section.*

Although the lower boundary has not been observed, a thick conglomerate sequence of mostly angular volcanic clasts is believed to be sitting unconformably on the "Volcanic Formation" of possibly Permo-Triassic age. This sequence is unstratified, with a few reverse-graded beds. Grain size decreases up the sequence and the middle part of the sequence is characterized by intercalated thin- to thick-bedded sandstone, siltstone and mudstone, displaying rather good lateral continuity. Maroon or reddish-brown is the predominant color but sandstone color can be light brown and grayish-green. Normally graded bedding and lamination are common, and channel structure and cross-bedding are rare. Thickness of sandstone beds, in general, decrease northward. The exposure at km 57+400 m may represent the middle part of the formation (Fig. 2.9 F). Here, the unit displays good lateral continuity of beds, small-scale cross-bedding and lamination. The upper part of the formation is not exposed but further north at km 6 on the Ngao-Song road (Fig. 2.8 C) it consists of normally graded, thin- to medium bedded, maroon and grayish-green mudstone and siltstone.

2.9.3 *Kilometer post 45+020 m to 45+425 m and 44+500 m to 44+650 m, on the Rong Kwang-Ngao highway sections: Reference section.*

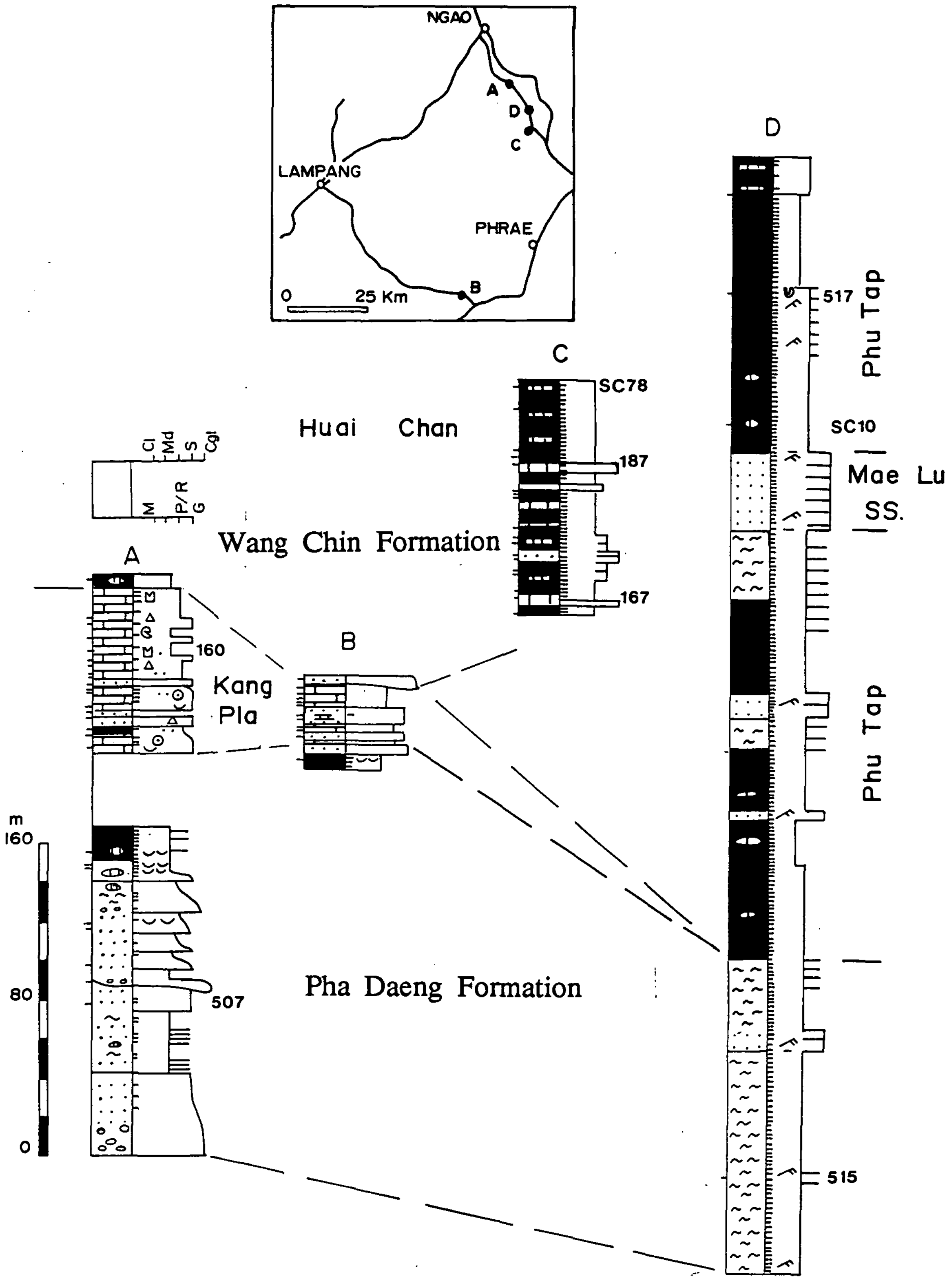
The Pha Daeng Formation in these sections has been mapped as the Phra That Formation (Piyasin, 1980; Liengsakul, 1979). It forms both limbs of an anticlinal structure. It unconformably overlies volcanic rocks of possibly Permo-Triassic or younger age. A good exposure on the western limb, 206 m thick, represents the whole sequence of the Pha Daeng Formation that conformably underlies the Kang Pla Formation and is the reference section of the formation (Fig. 2.10 A).

In the lower part of the member, matrix-supported conglomerate consisting mostly of volcanic clasts is unstratified. At least one reverse- to normally graded bed is present. There is also a crude imbrication as well as poor lateral continuity. The middle part is dominated by interbedding of sandstone and mudstone to siltstone. Sandstone is gray to grayish-green and coarse- to fine-grained, and commonly contains volcanic rock fragments. Siltstone and mudstone are maroon and grayish-green, and medium to thick-bedded, and feature calcareous concretions especially in maroon mudstone and rare cross-bedding. The concretions occur parallel to the bedding plane. There are also some dewatering structures (Fig. 2.9 G) and small-scale channel structures. The sandstone beds decrease in proportion up the sequence and give way to gray mudstone with minor limestone concretions which lie parallel to the bedding plane (Fig. 2.9 H). Abundant bivalves and brachiopods from this upper part were identified as *Palaeocardita singularis* and *Cassianella tenuistria* of early middle Carnian age (Chonglakmani,1981, p 433).

2.9.4 *Kilometer post 36+295 m to 35+950 m on the Rong Kwang-Ngao highway section.*

The Pha Daeng Formation at this section is 123 m thick and forms an eastern anticlinal limb. It conformably underlies the Wang Chin Formation. It consists mostly of thin-bedded to laminated, maroon or reddish-brown and grayish-green mudstones with thin beds or layers of greenish-gray siltstone and sandstone. Small-scale cross-stratification is common displaying a paleocurrent direction toward the east. The cross-stratification is 1-10 cm thick in each cycle and commonly displays normal grading and erosional basal surfaces (Fig. 2.9 I).

Fig. 2.10 Lithostratigraphic correlations of the Pha Daeng, Kang Pla, and Wang Chin Formations, **A**) and **D**) along the Rong Kwang-Ngao highway, **A**) km 45+020 m to 45+640 m, **B**) km 69 on the Lampang-Denchai highway, **C**) Huai Chan, and **D**) km 34+050 m to 36+295 m. Note all field sample numbers are preceded by PL, except where specified.


NGAO
A
D
C
LAMPANG
PHRAE
B
0
25 Km
D
517
Phu Tap
SC10
Mae Lu
SS.
Phu Tap
515
C
SC78
187
167
Huai Chan
Cl
Md
S
Cgl
M
P/R
G
Wang Chin Formation
A
160
Kang
Pla
B
m
160
80
0
507
Pha Daeng Formation

2.10 Kang Pla Formation

The Kang Pla Formation which takes its name from Doi Kang Pla, 10 km north of the Song District, was proposed by Chonglakmani and Tiyapun (1985) but no stratigraphic details were given. This name is favored here. Lithostratigraphic columns from the measured sections are shown in Figures 2.10 A, B.

Synonymy : Pha Kan Formation (only east of Phayao, Ngao and Long areas) of Piyasin (1972,1975), and Chonglakmani (1972,1981) ; Khun Huai Ri Formation (Chonglakmani and Tiyapun, 1985); Unit t'l in Ngao and east of Phayao (Baum and Hahn,1977).

Definition : The Kang Pla Formation is that sequence lying between the overlying Wang Chin Formation and the underlying Pha Daeng Formation. It consists mostly of thin- to massive-bedded, light gray to dark gray limestone and occurs mainly in the Phrae sub-basin. The type locality is situated at km post 45.5 on the Rong Kwang-Ngao highway.

Lithology : The Kang Pla Formation consists mainly of limestone with minor interbedded clastics. The limestone is light gray to dark gray and thin- to massively-bedded. The lithology varies laterally; in some areas oolite or skeletal grainstone is developed, in the others lime mudstone and peloidal packstone.

Thickness : The formation varies in thickness from the type locality at km 45.5 on the Rong Kwang-Ngao highway, where it is 76 m thick, to a section in the south at km 69 on the Lampang- Denchai highway, where it is 38 m thick. These two locations are possibly only the feather edges of a large lensoidal limestone body. At Ban Kaeng Luang, a thickness of about 500 m was reported by Chonglakmani (1981).

Regional extent : This formation is more widely distributed in the north (Long, Song, east of Ngao and Phayao areas) than in the south (Wang Chin area).

Contacts : It conformably underlies the Wang Chin Formation and conformably overlies the Pha Daeng Formation at about km 45.5 on the Rong Kwang-Ngao highway and east of the Ngao District (the Khun Huai Ri Formation of Chonglakmani and Tiyapun, 1985). It disconformably overlies the Permo-Triassic volcanics at Ban Pha Kho of the Long District (Chonglakmani,1981).

Paleontology and age : The formation ranges in age from middle Carnian to lower Norian. Middle Carnian *Halobia comata* and *Spiriferina* sp. were reported from gray limestone in Ban Pha Kho, 15 km north of Tam Bon Ban Pin (Chonglakmani,1981). The lower Norian conodont, *Epigondolella abneptis* , is found in limestone at km 69 on the Lampang-Denchai highway (identified by Dr. S.P. Carey, pers. comm., 1988).

Type section : It is proposed here that the section at km post 45+500 m to 45+625 m on the Rong Kwang-Ngao highway is the type section of the formation. For details see below.

2.10.1 *Kilometer post 45+500 m to 45+625 m, the Rong Kwang- Ngao highway section: Type section*

This section is the southern end of the "Doi Khun Huai Ri", a NS trending limestone mountain extending for more than 10 km. The Kang Pla Formation conformably overlies the Pha Daeng Formation (Fig. 2.10 A).

A 76 m thick sequence consists predominantly of limestone. The lower part consists mainly of oolitic and skeletal grainstone with minor packstone, wackestone, sandstone and mudstone (Figs. 2.11 A, B). Limestone is dark gray to gray, thin- to medium and wavy bedded and partly, especially in the upper part of the member, wrapped around by mudstone. Echinoderm fragments, bivalves and gastropods are common, and ostracods and dasyclads occur locally. Sandstone is gray, calcareous, medium to coarse-grained and medium bedded. The number of sandstone beds decreases up the sequence. Conversely wackestone and packstone beds increase. In general, bedding is thin to medium in thickness in the lower and upper part of the sequence, and thick to massive in the middle part. Sharp contacts may be observed between sandstone and limestone while gradational contacts may be observed between packstone and lime mudstone.

Based on its stratigraphic position and on paleontological data, it is clear that this section belong to the Kang Pla Formation. However, it was mapped as the Pha Kan Formation by Piyasin (1972) and as part of the Mae Tang Formation by Chonglakmani and Tiyapun (1985).

Fig. 2.11 Photographs of the Kang Pla and Wang Chin Formations.

A) Thin-bedded limestone of the Kang Pla Formation showing sandstone bed (SS) at the lower part of the sequence; at km 45.5 on the Rong Kwang-Ngao highway.

B) Nodular limestones occur in the upper part of the Kang Pla Formation, overlying the Figure 2.11 A.

C) Interbedded mudstone and limestone of Huai Chan Member at the type section, Huai Chan.

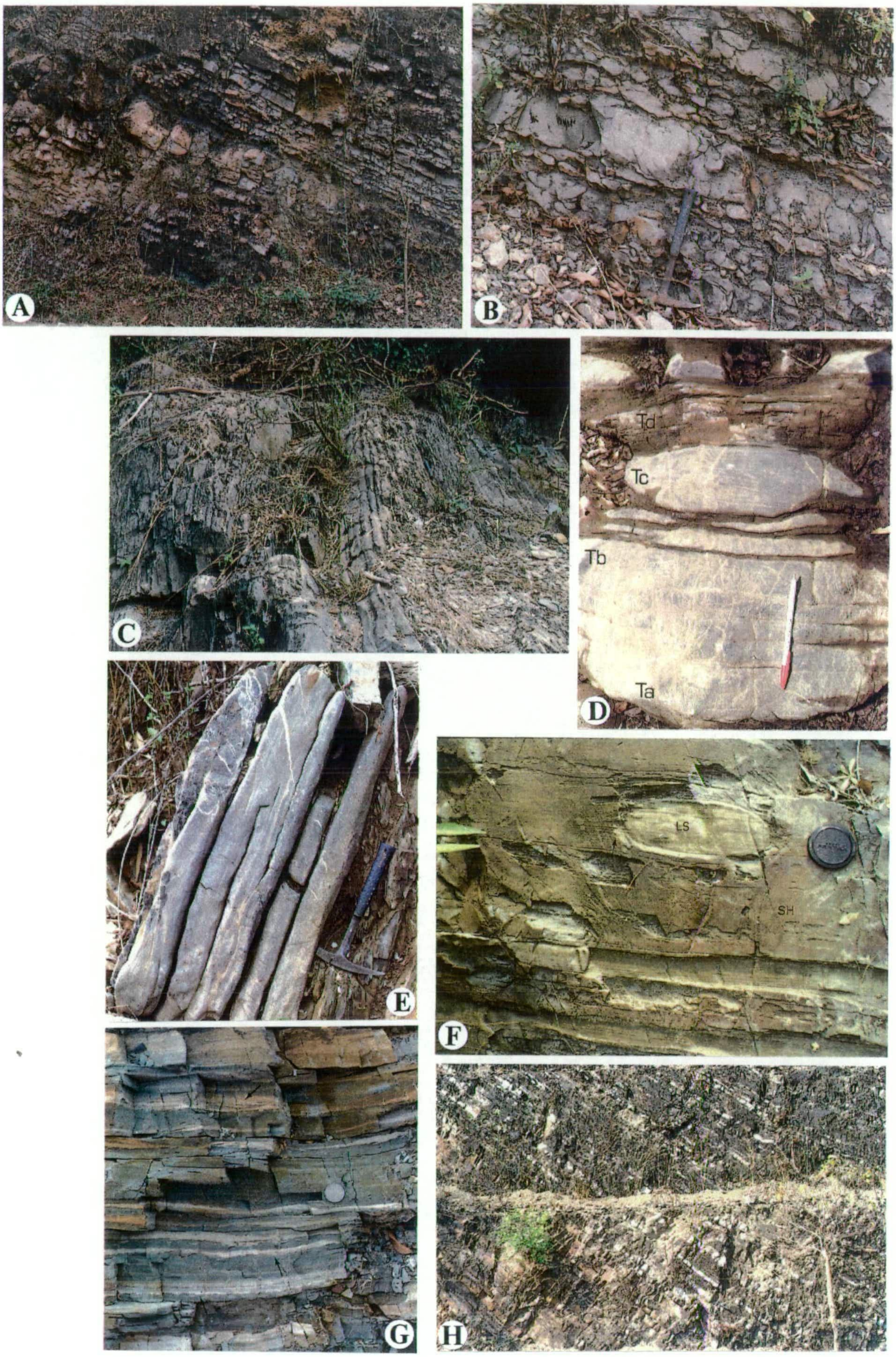
D) Turbiditic (allodapic) limestone of the Huai Chan Member showing Bouma Tabcd; at the type section, Huai Chan, Song District.

E) Another view of turbiditic limestone with Tab, Tabc; same location as Fig. 2.11 D.

F) Interbedding of laminated calcareous shale(SH) and limestone(LS). Note lenticular limestone and continuation of lamination from shale through to limestone with concave-up shaped occurring in shale (above the arrow); Huai Chan Member at Huai Chan west of Song District.

G) Sequence of shale, sandstone and chert of the Huai Chan Member contains load structures on the bottom side of sandstone bed (lower arrow) and cross-stratification (upper arrow); same location as in Fig. 2.11 D.

H) Interbedded sandstones and mudstones, where sandstones (lighter color and competent beds) are predominant over mudstones (darker beds). Sandstones are even, parallel and continuous beds, and often display normal grading. Note that the sandstones decrease in proportion up the sequence; Mae Lu Sandstone Member, km 34+470 along Rong Kwang-Ngao highway; hammer as scale at the lower middle.


A
B
C
Td
Tc
Tb
Ta
D
E
LS
SH
F
G
H

2.10.2 *Kilometer post 68+953 m to 69+000 m, the Lampang-Denchai highway section.*

The Kang Pla Formation at this section dips steeply nearly vertical. Load structures indicate top towards the northwest. It consists of 38 m of interbedded limestone and sandstone with minor conglomerate which conformably overlie tuffaceous rocks of the Pha Daeng Formation, containing an shallow marine bivalve *Pteria* (identified by Dr. C. Chonglakmani, 1990). Contacts between limestones and the overlying sandstones are generally sharp, and locally erosional surfaces are present. Limestones are intraclastic packstones to wackestones and lime mudstones; they are gray to dark gray and thin- to thick-bedded, and have a wavy and discontinuous bed type. Sandstone is gray, fine- to coarse-grained and wavy-bedded, and commonly contains volcanics and feldspar fragments. Volcanic rock fragments decrease upward in the sequence (westward). Normally graded beds from fine-grained conglomerate to sandstone occur locally. Conodonts of the *Epigondolella abneptis* zone indicate an early Norian age (identified by Dr. S.P. Carey, pers. comm., 1988).

A limestone quarry at Doi Pha Lak Mun, 1 km north of this location, consists of a thick sequence of thick- to massively bedded, dark gray peloidal packstone to wackestone and lime mudstone. Macrofauna is rare, but crinoids occur locally.

2.11 Wang Chin Formation

According to Wolfart (1987), the Wang Chin Formation was introduced by Charoenpravat (1968). This formation is widely distributed in the Wang Chin District. This name is adopted in this study following Wolfart (1987). However, its definition is different from that of Wolfart (1987) who compares it to the Hong Hoi Formation. It is subdivided here into three members as the Phu Tap, Huai Chan and Mae Lu Sandstone Members (Table 1.1). Lithostratigraphic columns from the measured sections are shown in Figures 2.10 and 2.12.

Synonymy : Synonymous are the Hong Hoi Formation (but only in the Song, Long and Wang Chin areas) of Piyasin (1972,1974,1975), Macdonald (1977), Bunopas (1981), Chonglakmani (1972,1981,1983), and Helmcke (1985); the Phra That Formation (Maneenai, et al.,1987); the Mae Wang Chang Formation (Sukvattananunt and Paksamut,1986); and the Wang Chin Formation (Wolfart, 1987) but only in the Wang Chin area.

Definition : The Wang Chin Formation is that sequence lying between the underlying Kang Pla Formation or Pha Daeng Formation, and the overlying Jurassic strata. It occurs in the Phrae sub-basin and consists mainly of mudstones with subordinate turbiditic sandstones and allodapic limestones. It is subdivided into three members as the Huai Chan, Mae Lu Sandstone, and Phu Tap (Table 1.1). *Halobia* is a typical fossil and often occurs in the Mae Lu Sandstone and Phu Tap Members. The type locality of the Huai Chan Member is at Huai Chan. The type localities for the Mae Lu Sandstone and the Phu Tap Members are between km 54+730 m and 55+930 m, and between km 66+350 m and 66+770 m on the Lampang-Denchai highway.

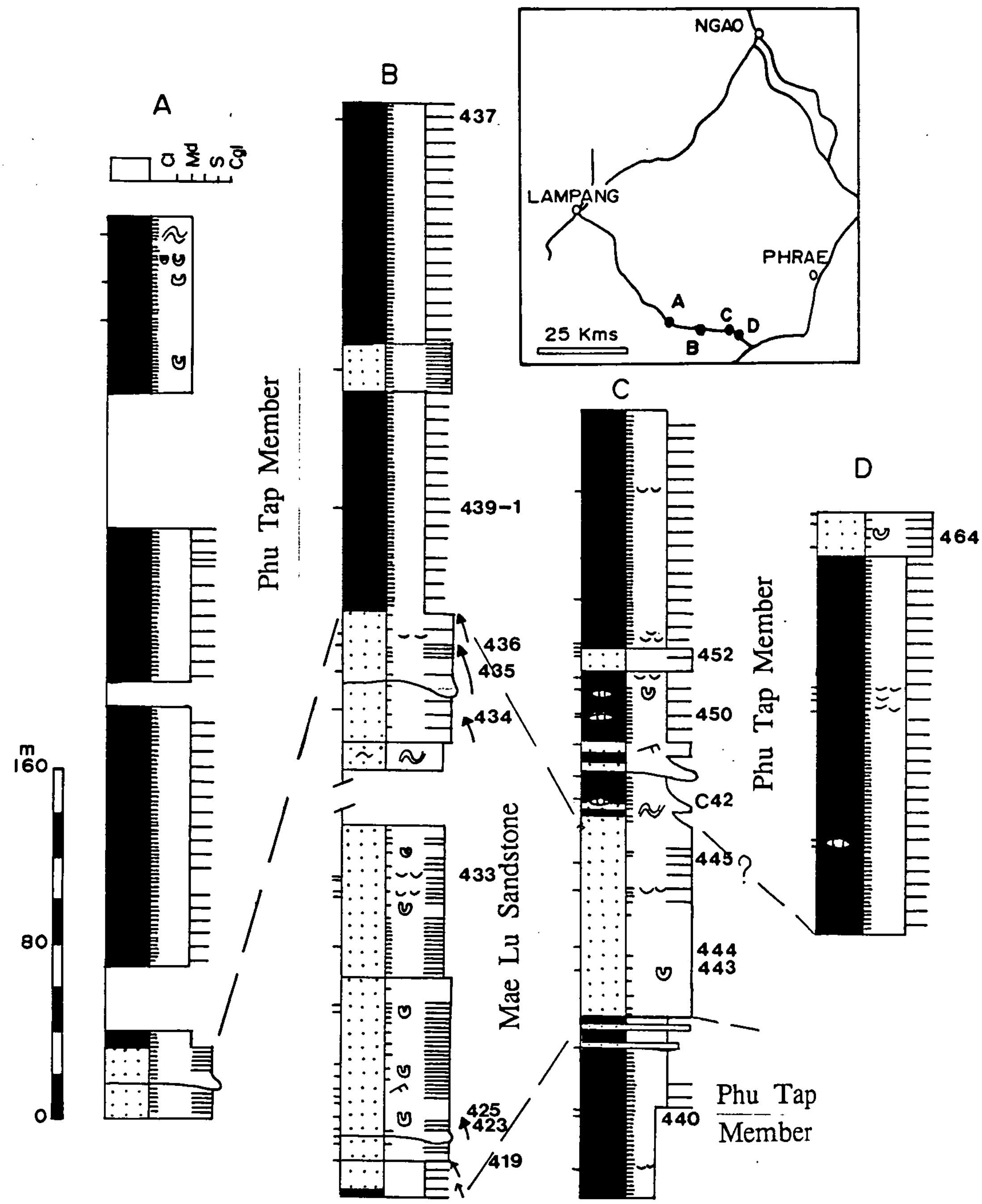
Lithology : The formation consists of three members:

Phu Tap Member : This member takes its name from the Phra That Phu Tap temple which is situated at km 50.6 on the Lampang-Denchai highway. It consists mainly of gray to greenish-gray, laminated to thin- bedded to structureless mudstone with minor fine-grained sandstone and siltstone beds or lenses. *Halobia* is common. Lithologically, this member is similar to both the Huai Chan and the Mae Lu Sandstone Members. It is distinguished from the Huai Chan and the Mae Lu Sandstone Members by the scarcity of limestone and sandstone, respectively.

Huai Chan Member : Takes its name from Huai Chan where exposure is good. The Huai Chan Member is characterized by alternating beds of gray to dark gray limestone, mudstone and shale with minor sandstone and chert beds. Limestone is laminated and thin- to medium bedded, often ~~containing~~ exhibiting Bouma sequence. Normally graded beds and lamination are common. Load, convolute, and sedimentary slump structures occur locally.

Mae Lu Sandstone Member : Takes its name from Ban Mae Lu situated along the Lampang-Denchai highway. It is characterized by mainly sandstone beds intercalated with subordinate mudstone. The sandstone is gray to light brown, fine- to coarse-grained and thin- to medium bedded with occasional thick beds. Sandstone beds usually display planar bases and normal grading, and cross-bedding is rare. The mudstone is similar to that of the Phu Tap Member. *Halobia* may be common to abundant in the mudstone.

Fig. 2.12 Lithostratigraphic correlations of the Wang Chin Formation from the measured sections along Lampang-Denchai highway showing the Phu Tap and Mae Lu Sandstone Members. **A**) km 45+520 m to 46+500 m, **B**) km 54+730 m to 55+930 m, **C**) km 66+350 m to 66+770 m, and **D**) km 68+300 m to 68+600 m. Note all field sample numbers are preceded by PL, except where specified.



A
B
C
D
Cl
Md
S
Cgl
m
160
80
0
437
439-1
436
435
434
433
425
423
419
452
450
C42
445
444
443
440
464
Phu Tap Member
Mae Lu Sandstone
Phu Tap Member
Phu Tap Member
NGAO
LAMPANG
PHRAE
25 Kms

Thickness : There is no single complete section. The formation is estimated to be about 600 to over 1,000 m thick. The Huai Chan Member at the type locality is 110 m thick. The Mae Lu Sandstone Member is 40, 230 and 100 m thick at km post 34+470 m to 34+550 m on the Rong Kwang-Ngao highway, at km post 55+190 m to 55+930 m, and 66.4 to 66+555 m on the Lampang-Denchai highway, respectively. The thickness of the Phu Tap Member is 400 m at km post 34+050 m to 35+950 m on the Rong Kwang-Ngao highway, and 370, 230 and 190 m at km post 45+520 m to 46+500 m, 54+730 m to 55+190 m and 66+350 m to 66+555 m on the Lampang-Denchai highway, respectively.

Regional extent : It mainly occurs in Wang Chin, Long, east of Ngao and possibly east of Phayao areas.

Contacts : It conformably underlies clastic rocks of possibly Jurassic age (the Unit J1-1 of Chonglakmani and Kenvised,1986). Along the Rong Kwang-Ngao highway, it conformably overlies both the Kang Pla and Pha Daeng Formations. At Ban Thung Laeng, 22 km NE of Wang Chin District, it rests disconformably on Permian limestone and shale (Chonglakmani,1981).

Paleontology and age : Only middle Carnian to lowermost Norian fossils have been reported from this formation. At Ban Thung Laeng, 22 km NE of Wang Chin, *Halobia styriaca* and *Halobia cassiana* of middle Carnian age were reported from gray shale and siltstone 150 m above the base of the formation, possibly equivalent to the Phu Tap Member, which lies disconformably on Permian limestone and shale. Lowermost Norian bivalves were reported from Ban Dok Kham Tai of Ngao, Huai Puy of Song, and Ban Mae Saliam Wan of Thoen (Chonglakmani,1981). The Middle Carnian *Halobia styriaca* was also observed from the Mae Lu Sandstone at km 55 + 542 m on the Lampang-Denchai highway.

Type locality : Type localities are proposed here for the Huai Chan Member at Huai Chan of Song District, and for the Mae Lu Sandstone and Phu Tap Members at km 54+730 m to 55+930 m and 66+350 m to 66+770 m along the Lampang-Denchai highway (Figs. 2.12 B, C).

2.11.1 *Huai Chan section: type locality*

A good exposure crops out along a small creek called Huai Chan (grid reference 200433, sheet 5045-4, Amphoe Song), east of the Huai Chan irrigation reservoir or 6 km west of the Song District of Phrae Province. The base of the measured section is situated at the first prominent shale outcrop on the west flank of the creek, next to the walking-track up to the creek margin. The top of the section is located at the outcrop under the bridge to the reservoir.

This 110 m thick sequence is the type section of the Huai Chan Member and is characterized mainly by interbedded limestone, shale and mudstone with a few sandstone and chert beds (Figs. 2.10 C and 2.11 C). Shale is gray, calcareous and laminated to thin-bedded. Limestone, commonly with graded beds and lamination, is gray to dark gray, thin- and wavy-bedded. Some are clearly turbiditic limestones (Figs. 2.11 D, E) or allodapic limestone of Meischner (1964). Some are nodular limestones in which the nodules are elongated parallel to the bedding plane. Some laminae can be traced from shale through nodular limestone (Fig. 2.11 F). Both sharp and gradational contacts occur between shale and limestone. The sandstone is gray on fresh surfaces and light brown when weathered, medium to fine-grained, thin-bedded to laminated, dense textured and associated with shale and chert. Current ripples and cross-stratifications occur locally in limestone and sandstone indicating that the paleocurrent direction was to the northeast. Convolute and load structures are common to abundant in the sandstone and chert (Fig. 2.11 G). A small scale syndepositional fault is observed in shale from the middle part of the section and there are sedimentary slump structures in the upper part. Macrofauna is rare and of low diversity. Among them echinoderms are relatively common.

2.11.2 *Kilometer post 34+050 m to 35+700 m, Rong Kwang-Ngao highway section.*

The Wang Chin Formation, at this location, consists of two members (Fig. 2.10 D), the Phu Tap and Mae Lu Members, which form the eastern limb of the anticline. The Wang Chin Formation conformably overlies the Pha Daeng Formation, and the upper boundary is not seen.

Phu Tap Member : This member splits into two parts that are separated by the Mae Lu Sandstone Member (Fig. 2.10 D). The lower part of the member (224 m thick) is predominantly thin-bedded to laminated, greenish-gray mudstone with interbedded thin layer (generally less than 1 cm thick) of light gray siltstone.

Limestone nodules occur locally and lie parallel to the bedding plane; some display graded beds. Small-scale cross-stratification (amplitude 1-3 cm) is common and eastward-trending paleocurrent is indicated. The upper part of the member, about 150 m thick, consists of a thick sequence of thin- to medium bedded, greenish-gray mudstone intercalated with thin beds or lenses of lime mudstone and light gray siltstone to fine-grained sandstone. Normal graded beds and small-scale cross-bedding are common. Trace fossils (possibly *Chondrites* , identified by Dr. MR. Banks, pers. comm., 1990) occur locally. Conodonts from limestones at this location belong to the *Epigondolella abneptis* zone of early Norian age (identified by Dr. S.P. Carey, pers. comm., 1988).

Mae Lu Sandstone Member : A 40 m thick sequence is characterized by interbeds of even and parallel, thin- to medium bedded graywacke (Fig. 2.11 H) and minor thin-bedded, greenish-gray mudstone to siltstone. Normal grading is common, and lamination and cross-stratification occur locally.

2.11.3 *Kilometer post 45+520 m to 46+500 m, the Lampang-Denchai highway section.*

This 410 m thick section consists of two members, the Phu Tap and the Mae Lu Sandstone Members.

Mae Lu Sandstone Member : The Mae Lu Sandstone at this section is about 40 m thick consisting of even, parallel and thin beds (normally 3-5 cm thick but up to 15 cm) of fine-to medium grained gray sandstone and a few gray mudstones (Fig. 2.12 A). Sandstone which is commonly feldspathic has abrupt and sharp contacts with the underlying mudstone and often shows sole markings. Neither the upper nor the lower boundary of the member is observed, but the bedding orientation is conformable with the overlying member, the Phu Tap.

Phu Tap Member : It consists mainly of gray to greenish-gray mudstone with minor thin beds or layers of fine-grained sandstone to siltstone. The upper part of the section contains abundant vertical and horizontal burrows of single-hole type which are filled with sandstone. Fauna is rare in this intensely burrowed zone. Disturbed beds occur in this upper part (Fig. 2.13 A). The sequence is unconformably overlain by coarse grained arkose displaying a coarsening upward sequence.

Fig. 2.13 Photographs of the Wang Chin Formation.

A) Slump structures in the Phu Tap Member. Note nearly horizontal beds (above the hammer); km 46.5 along Lampang-Denchai highway.

B) Thinning-and fining-upward sequences in interbedded sandstone (lighter beds) and mudstone (darker beds). Burrows and fossil wood fragments are also common; Mae Lu Sandstone Member at km 55+800 on the Lampang-Denchai highway.

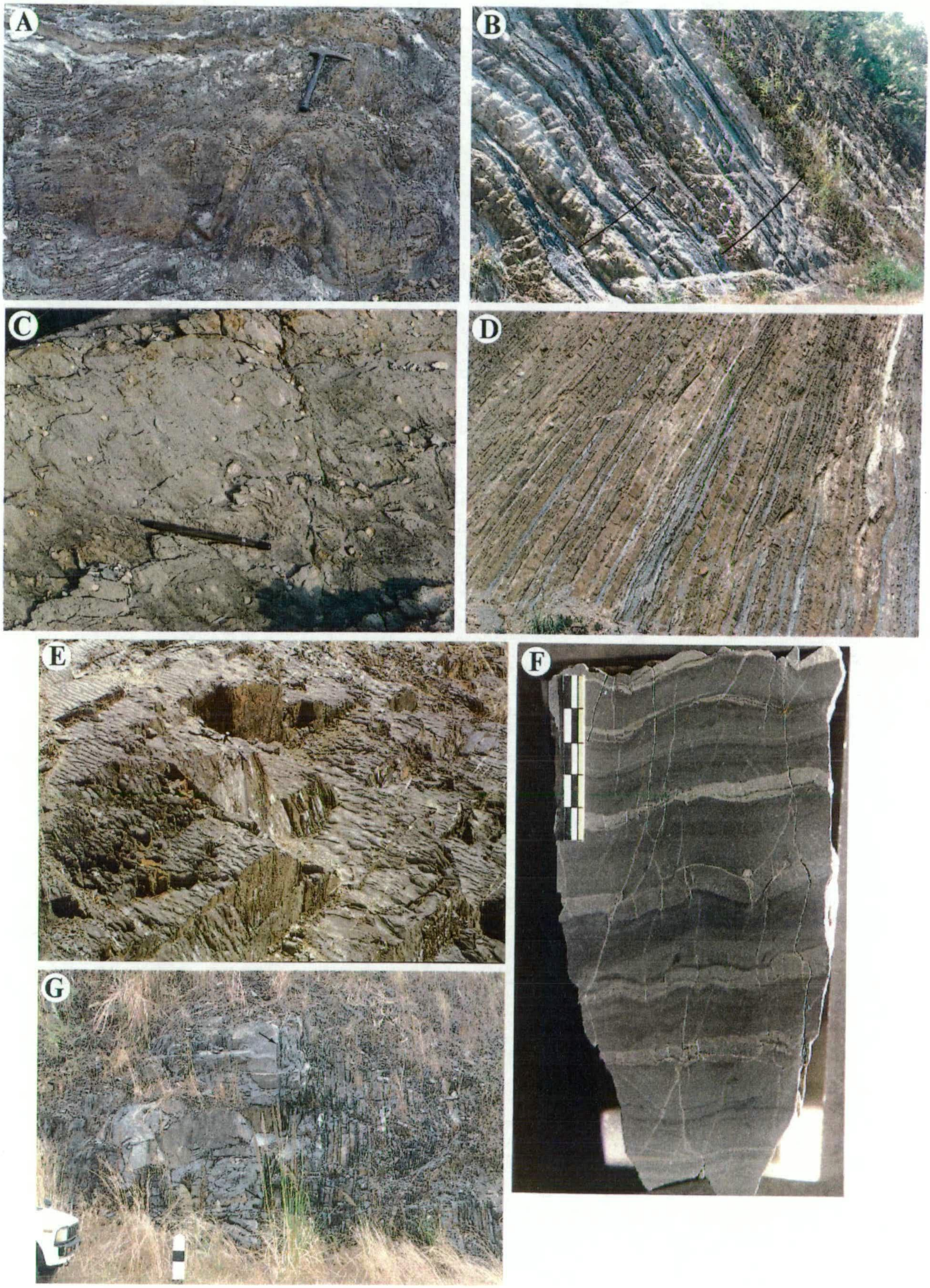
C) Enlargement from Figure 2.13 B. Burrows are filled with sandstone, mainly vertical types and have both double and single holes. Pen diameter is 1 cm. Photo was taken approximately perpendicular to bedding plane; Mae Lu Sandstone Member at km 55+850 m, the Lampang-Denchai highway; field sample number PL 423.

D) Mae Lu Sandstone Member with even, parallel and continuous beds of thin- to thick-bedded sandstone (thicker beds) and mudstone (thinner). Note obscured thinning and fining upward of sandstone beds; at km 55+240 m on the Lampang-Denchai highway.

E) Photo showing both boudinage and mullion structures in mudstone and thinly interbedded sandstone sequence of the Phu Tap Member. These corrugated structures occur parallel to the bedding plane; at km 54+800 m, the Lampang-Denchai highway.

F) Polished slab displaying mudstone and thinly interbedded fine-grained sandstone to siltstone. Normal grading is common; same location as the Fig. 2.13 E (positive position); field sample number PL 437.

G) Massively bedded sandstone (up to 2 m thick), with a flat-based bed (arrow), interbedded with thin- to medium bedded sandstone; Mae Lu Sandstone Member at km 66+540 m on Lampang-Denchai highway. Top to the left of the photo.


A
B
C
D
E
F
G

2.11.4 *Kilometer post 54+730 m to 55+930 m Lampang-Denchai highway section*

The Wang Chin Formation in this section consists of two members: the Mae Lu Sandstone Member in the lower part, and the Phu Tap Member in the upper part (Fig. 2.12 B).

Mae Lu Sandstone Member : This member is 230 m thick. Its lower contact at km post 55+930 m is faulted against red slaty shale of possibly Permian age, while the upper boundary grades into the overlying Phu Tap Member. It consists of alternating beds of sandstone and mudstone commonly with fining upward cycles which normally commence with coarse-grained sandstone, grading up to siltstone and mudstone. There are also thinning- and fining-upward sequences of sandstone beds, about 2 m thick in each sequence (Fig. 2.13 B). Sandstone commonly with feldspar and muscovite is gray, medium to fine-grained and thin- to medium bedded. Low amplitude sole markings occur locally. Contacts between sandstone and the underlying mudstone are usually sharp, but they are both sharp and gradational with the overlying mudstone. Fossil wood or coalitized plant fragments occasionally occur and lie parallel on sandstone beds. Burrows, mostly vertical of twin and single hole types (Fig. 2.13 C), are common in the mudstone. At km 55+875 m trace fossils (may belong to *Chondrites* , identified by Dr. MR. Banks, pers. comm., 1990) were observed. The burrows measure 0.5-1.0 cm in diameter, about 4 cm in length, and are filled by sandstone. They are commonly accompanied by worm traces. Cross-stratification is rare. Nevertheless, it may indicate a paleocurrent direction toward the south.

The upper part of the member consists of couplet-beds of sandstone and mudstone (Fig. 2.13 D). Sandstones are fine- to coarse-grained, thin- to medium bedded, mostly parallel and good lateral continuity bedding with partial sole markings on the bottom surface (PL 435). Some sandstone beds wedge out laterally with their lower part usually containing fine grained conglomerate grading up to sandstone. These beds probably belong to broad channel structures.

Middle Carnian *Halobia styriaca* (identified by Dr. C. Chonglakmani, pers. comm., 1990) occurs in white tuffaceous shale from the middle part of the member. These bivalves lie mostly convex-side up.

Phu Tap Member : A 220 m thick sequence conformably overlies the Mae Lu Member with transitional contact. It is characterized by a thick sequence of thin- to medium beds of gray mudstone and intercalation with thin layer (normally about 1-5 cm thick, but up to 30 cm) of light gray, fine grained sandstone to siltstone. Some siltstones and sandstones are lens shaped occurring parallel to the bedding plane. These were possibly caused by tectonic movements. The intersection of the bedding plane and cleavage creates a corrugation on the bedding surface (Fig. 2.13 E) or mullion (Hobbs et al., 1976, p 276). Contact of sandstone with the underlying mudstone is generally sharp and normally graded beds are common (Fig. 2.13 F).

2.11.5 *Kilometer post 66+350 m to 66+770 m Lampang-Denchai highway section.*

It consists of two members, the Phu Tap and Mae Lu Sandstone Members. The latter member may be surrounded by the former.

Phu Tap Member : Clayshale with minor mudstone is dominant in the lower part and grades up to gray mudstone interbedded with thin layers (generally 1 cm, but up to 15 cm thick) of sandstone and siltstone. The clayshale is gray, displaying papery partings, and has a greasy feel; mica is common. In the upper part, it is dominated by laminated to thin-bedded, gray mudstone and minor sandstone. The lamination in the mudstone is formed by alternating mudstone and siltstone or fine-grained sandstone. Sandstone is common close to the Mae Lu Member. Sandstone is gray, fine- to coarse-grained, generally thin-bedded with occasional thick beds. Low amplitude sole markings and mud blebs are common but channel structures and ripple marks are rare. The mudcracks reported by Helmcke (1986b) in this area are considered as joint traces in this study. The joints also cut the bivalves which are abundant.

Bivalves, burrows and trace fossils are commonly present, and most of the bivalves are convex-side up. Late Carnian *Halobia charylana* occurs in the upper part of this section (UTGD no. 12387, identified by Dr. C. Chonglakmani,1990).

Mae Lu Member : The transitional boundary between the Mae Lu Sandstone Member and the Phu Tap Member is represented by an upwards increase in the proportion of sandstone. Sandstone is gray, fine- to coarse-grained, thin- to massively bedded, up to 2 m thick (Fig. 2.13 G). Beds generally display flat bases and normal grading is common. There are also some small-scale load structures, fossil wood and black shale flakes which lie parallel to sandstone beds. Burrows with double and single holes of mostly vertical types, similar to those at km 54+730 m to 55+930 m along the Lampang-Denchai highway, are common. *Posidonia* and worm tubes occur locally in the middle part of the member.

2.11.6 *Kilometer post 68+315 m to 68+600 m Lampang-Denchai highway section.*

Phu Tap Member : This 310 m thick section consists mainly of massively bedded, greenish-gray to gray mudstone with interbeds of thin layers or lenses of fine-grained sandstone and siltstone. There are also a few lenses of limestone lying parallel to the bedding plane. The limestone consists of thin-shelled bivalves. Laminated mudstone occurs especially in the middle part of the section. The lamination is shown by alternating layers of lighter and darker colors, and the darker often grades to the lighter. Sandstone is commonly burrowed, medium to coarse-grained and thick- to medium bedded and occurs in the upper part of the section. Bivalves *Halobia* and trace fossils *Planolites* and *Chondrites* (identified by Dr. MR. Banks, pers. comm., 1990) are common.

Chapter 3 : Carbonate Sedimentology of the Lampang Group

3.1 Introduction

There are three carbonate formations within the predominantly siliciclastic Lampang Group, namely the Pha Kan, Doi Long and Kang Pla Formations. The Pha Kan and the Kang Pla Formations are underlain by red beds, and overlain by deeper marine clastic turbidites, suggesting transgressive sequences. Conversely, the Doi Long Formation represents part of a regressive sequence with a marine turbiditic sequence below and with red beds above.

In order to present detailed carbonate microfacies and depositional models for the Lampang Group, the microfacies are interpreted on the basis of microlithology, type of allochems, bedding type, paleontology, and facies associations. Allochem types, in particular oncoids and ooids have long been used to aid depositional environmental interpretation (Peryt, 1983b; Wright, 1983; Ratcliffe, 1988). Geometric criteria, on the other hand, are impossible to apply due to poor lateral exposure.

The following sections will discuss:

- Previous work (3.2)
- Petrography of oncoids and ooids with respect to their depositional environments (3.3 & 3.4)
- Details of microfacies (3.5).
- Depositional models for the Lampang carbonates (3.6).

3.2 Previous carbonate sedimentological studies

There have been no previous carbonate facies analyses of the Lampang Group. Previous investigators (e.g., Piyasin, 1972; Bunopas, 1981; Chonglakmani, 1981; Helmcke, 1985; Wolfart, 1987) suggested that the Lampang Group carbonates were deposited in a shallow marine platform setting, largely on the evidence of oncolites and oolites. Although the oncolites are found almost exclusively in the Pha Kan Formation, the majority of the Lampang carbonates also represent shallow marine environments. A few allodapic limestones occur and this study is the first to recognize these.

3.3 Oncoid petrography

According to Monty (1976), oncoids can be subdivided into two types; spongiostromate fabric consisting of micrite and spar, and porostromate fabric consisting of filaments, algal tubes and micritic threads. Oncoids can be formed under rolling and/or static conditions (Jones and Wilkinson,1978; and Peryt,1983a). Because of rolling and abrasive effects, the percentage of porostromate fabric preserved in oncoid cortices decreases as depositional energy increases (Wright,1983; and Ratcliffe,1988). Consequently, oncoids formed in higher energy environments are subspherical and rounded, well laminated and have a dense fabric, while oncoids of lower energy are irregularly shaped and less well laminated, and have a spongy fabric.

Oncoids are typically restricted to the Pha Kan Formation, particularly the Wiang Sawan and Muang Kham Members. Three morphological types of oncoids can be distinguished; herein named Type A, B and C. Oncoids of each type are likely to be restricted to specific facies.

Type A : Oncoids with dominant spongiostromate fabric

The cortices of Type A oncoids consist mainly of gray spongiostromate fabrics that display a few discontinuous concentric laminae of dark gray porostromate fabrics (Fig. 3.1 A). The oncoids are rounded, subspherical to irregular in shape; have spongy fabrics; and range in size from 1 cm to 3 cm. The outer cortices may display an algal cauliflower structure and may branch. Branching cortices are common where the matrix consists mainly of micrite. The matrix, on the other hand, is dominated either by peloids or micrites. The porostromate fabrics are thinly laminated (normally on a micron scale, but their thickness varies within a lamina and some may converge).

Algal tubes may be observed but are poorly preserved. Peloid-filled borings are common on the cortices (Fig. 3.1 A). Fauna such as gastropods, bivalves and echinoderms are common, and serve as the nuclei of the oncoids. The shape of the oncoid depends on the shape of the nucleus.

Type A oncoids usually occur in oncolitic-peloidal packstones and oncolitic wackestones. They are dominant in the Wiang Sawan and Muang Kham Members of the Pha Kan Formation.

Type B : Rounded oncoids

Type B oncoids are rounded, spherical to subspherical in shape and normally less than 1 cm in diameter. They have a dense fabric consisting mainly of spongiostromate with rare discontinuous dark gray algal laminae (porostromate) (Fig. 3.1 B).

Type B oncoids are not common in the Lampang Group. They occur locally in the Pha Kan Formation.

Type C : Oncoids with dominant porostromate fabric

Type C oncoids consist mainly of dark gray porostromate fabrics such as algal tubes and laminae (Fig. 3.1 C). They are irregular in shape, well laminated and normally smaller than 2 cm in diameter. Branching and columnar structures are common.

Type C oncoids occur in the regressive limestone sequence in the Doi Long Formation.

Interpretation : Algae are generally accepted to be indicative of shallow water deposits. They prosper within the photic zone, normally at a water depth of less than 50 m on carbonate platforms, although they have also been found at depths of 1,000 m in the Indian Ocean (Ratcliffe, 1988). Peryt (1983a) concluded that oncoids are mostly associated with slow sedimentation rates.

Type A oncoids consist mainly of spongiostromate fabrics with a few concentrically laminated porostromate fabrics. This suggests they formed in agitated water under intermittent rolling conditions, but that the current energy was not strong enough to create good concentric lamination in their cortices (Wright,1983). Common to abundant borings on the cortices indicate that the oncoids formed in low-energy conditions. Type A oncoids are also similar to the restricted environment oncoids of Aigner (1985).

Fig. 3.1 Photomicrographs showing petrography of oncoids and ooids of the Lampang Group.

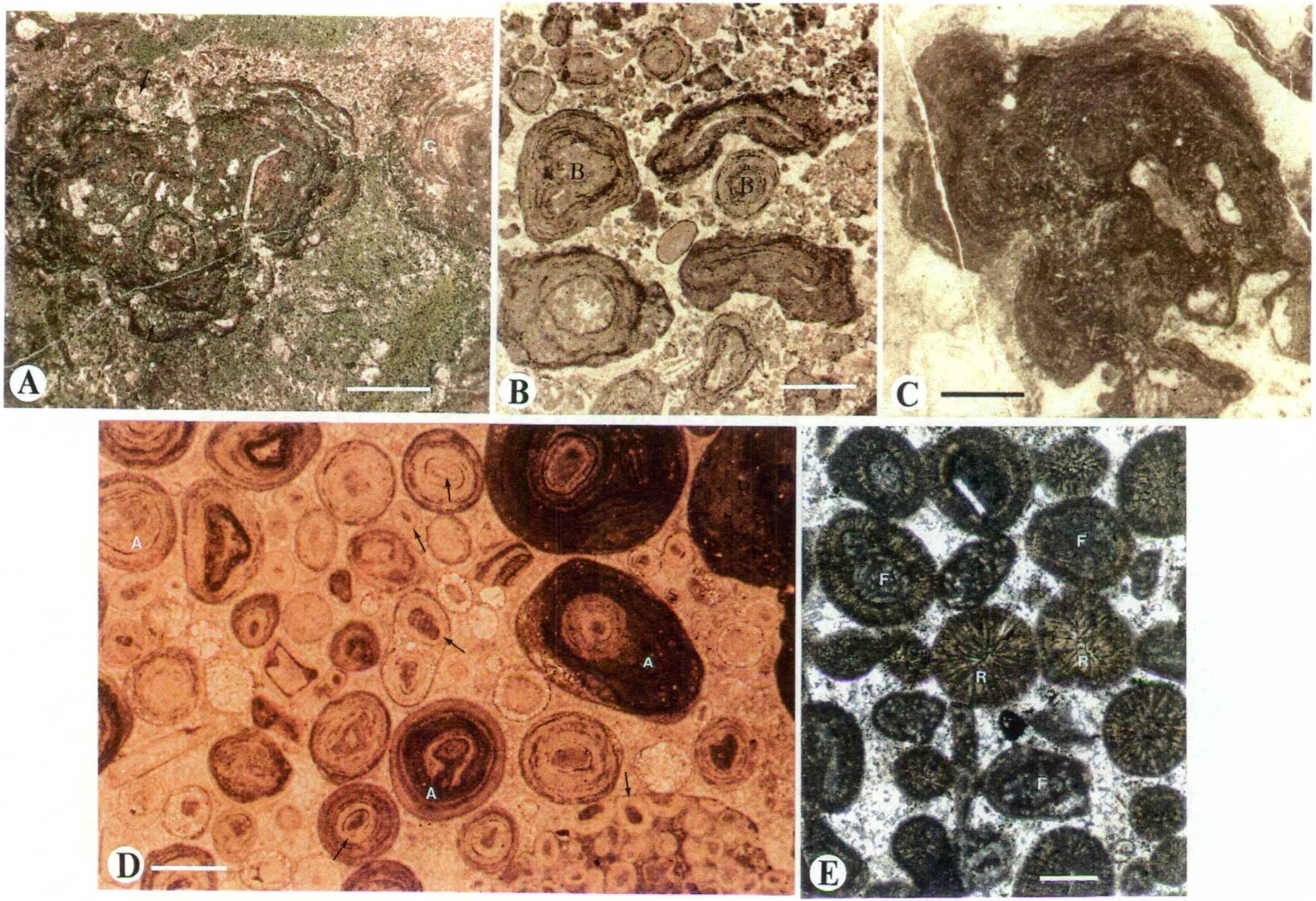
A) Type A oncoids showing round cortices, rare branching form and irregular asymmetrical morphologies. Note borings (arrow) in the cortices, cauliflower structure (C), and replacement dolomites (green); stained thin section, sample no PL 309, Wiang Sawan Member at Phra Thu Pha quarry. Bar scale is 3 mm.

B) Type B oncoids (B) have a dense fabric and are well rounded, and show mainly spongiostromate fabric; at 200 m SW of Fig. 3.1 a. Bar scale is 1 mm.

C) Type C oncoid shows mainly porostromate fabric with an irregular shape; sample no PL 379, Doi Long Formation at Doi Pha Bong. Bar scale is 2 mm.

D) Type A ooids (A) showing fibrous concentric cortices. Note similarity in size and texture between the inner cortex of Type A ooids (arrow) and smaller ooid (arrow); sample no PL 53, Wiang Sawan Member at Phra That Muang Kham temple. Bar scale is 1 mm.

E) Type B ooids showing dark-ray radial cortex (R). Note foraminifera (F) as the nucleus of ooid; sample no C3, Chang Garb Member at Doi Chang. Bar scale is 200 microns.


A
C
B
B
B
C
D
A
A
A
E
F
F
F
R
R

The absence of less resistant and branching cortices in Type B oncoids, in addition to their dense fabric, spherical to subspherical shape and better developed lamination, strongly suggest a greater degree of rolling. On the other hand, there is an indication that spongiostromate fabrics themselves are formed under relatively high energy conditions (Peryt, 1983a; Wright, 1983; Ratcliffe, 1988). This interpretation is supported by lack of bioturbation on the cortex and the fact that Type B oncoids are always associated with grainstone. By analogy, Type B oncoids are similar to the dense oncoids forming in high energy conditions (Wright,1983).

Type C oncoids show mainly porostromate fabrics and have irregular shapes suggesting that they formed in calm conditions. These oncoids occurred in a regressive sequence suggested by the upward grading of limestones to the red beds of the overlying Pha Daeng Formation.

3.4 Ooid petrography

Ooids are volumetrically not as important as oncolites in the Lampang carbonates. Two main types of calcareous ooids are recognized. The cortices of both types display mainly radial structure with micritic patches, but the occurrences of the micritic patches within them are different. One shows a radial fabric and the other a concentric fabric. These differences are usually related to a specific depositional facies, but in some instances ooids of different types may coexist in the same sample.

Type A : Ooids with radial-fibrous cortex and a few concentric patches

Type A ooids have cortices displaying a finely preserved radial-fibrous fabric which often alternates with a few concentric micritic patches or banding (Fig. 3.1 D). When ooids are small (< 300 μm in diameter), the cortices show no concentric micritic patches. As they increase in size, their outer cortex displays concentric micritic patches with interlaminated radial-fibrous fabrics. Micritization is common. Ooids are light brown to brown in plane-polarized light, inclusion-rich, mostly spherical but elongated shapes also occur depending on the shape of the nucleus. Dissolution features are common in the outer part of the cortices. Ooids range in size from 100 to 1400μm (average diameter is 500 μm). The ooids' nuclei are mainly peloids (normally 100-200 μm in size) with some skeletal grains. Nucleus to cortex ratios range from 2:1 to 1:3. Type A ooids usually occur in poorly sorted grainstone and are often associated with composite ooids, oncoids and diverse fossils.

Type A ooids are similar to the radial-concentric ooids of Heller et al. (1980) in Tucker (1984), banded-radial ooids of Wilkinson and Landing (1978), and Medwedeff and Wilkinson (1983); and to the radial ooids of Swirydczuk (1988).

Type A ooids are exposed at Phra That Muang Kham temple and the Doi Nok sections. The ooids in these two locations are different in that the former contains blocky ooids (Chow and James, 1987) as well as broken and composite ooids indicating relatively higher water energy.

Type B : Ooids with coarsely preserved radial cortex and dark rays

These ooids are characterized by coarsely preserved radial cortices displaying vague, dark micritic rays. They rarely show fibrous texture (Fig.3.1 E). They contain a higher content of inclusions than Type A ooids, are brown in thin-section, spherical to sub-spherical in shape and range in size from 100 to 400 µm. The cortex thicknesses are less variable (about 50 to 100 µm). The nuclei of ooids consist mainly of peloids (average diameter, 40 µm) and foraminifera. Foraminifera are the only fauna that are common to abundant.

Type B ooids within the measured sections are restricted to the Chang Garb Member.

Interpretation : Type A ooids, consisting of concentric cortices, are comparable to present day ooids formed in high-energy agitated environments of the Persian Gulf (Loreau and Purser, 1973) and the Bahama Banks (Dr. E. Purdy, pers. comm., 1990). As suggested by Loreau and Purser (1973), ooids forming close to a terrigenous influx have nuclei of siliciclastic grains, whereas those forming in areas remote from such influx have autochthonous carbonate nuclei. The nuclei of Type A ooids consist mainly of peloids suggesting that the ooids formed in an environment remote from siliciclastic influx. The small ooids, displaying radial-fibrous cortices, probably remained mainly in suspension under high energy conditions that permitted the accretion of a radial cortex without severe grain abrasion (Heller et al., 1980). The radial fabrics reflect a less turbulent environment than concentric fabrics (Tucker,1984; Strasser,1986). When size increases, bed-load transport becomes more significant and results in growth of concentric laminae and grain breakage (Chow and James, 1987).

Type B ooids are interpreted as being deposited in a restricted or lagoonal environment. This interpretation is supported by the close associations with a restricted fauna. Ooids like those of Type B were reported from a modern lagoonal setting in the Persian Gulf (Loreau and Purser, 1973). Type B ooids are also similar to the lagoonal ooids (Type 5) of Strasser (1986). Tucker(1984) suggests that the formation of dark-rays within the cortex occurs in a less turbulent environment where some lime mud is present.

3.5 Carbonate microfacies

The Lampang Group ~~consists~~ contains of six carbonate units: the Wiang Sawan Member, Muang Kham Member, Cave Temple Member, Doi Long Formation, Kang Pla Formation, and the Huai Chan Member. Most of these were formed in shallow marine subtidal environments, except the Huai Chan Member which consists of limestone turbidites suggesting a deep marine environment.

Petrographic analysis proved to be the most useful tool for determining both depositional environments and stratigraphy of the Lampang Group~~,~~ carbonates since some allochems are largely restricted to particular stratigraphic units. The Wiang Sawan and Muang Kham Members consist mainly of oncolites with minor oolites, peloidal grainstone and dasycladacean grainstone. The Cave Temple Member and the Doi Long Formation are massive-bedded, pure carbonates and consist mainly of skeletal and peloidal packstone to wackestone in which algae are common to abundant. Peloidal algal packstone is almost entirely restricted to the Doi Long Formation. Recrystallization, however, tends to obscure many of the original sedimentary textures. It is difficult to estimate the exact percentages of carbonate sediment types in the Kang Pla Formation due to limited data. However, within the measured sections, the formation is dominated by skeletal grainstone to wackestone. Turbiditic limestones occur mainly in the Huai Chan Member and partly in the Huai Muang Member.

Fourteen microfacies are recognized on the basis of lithology, sedimentary structures and fossil content in addition to the morphology of oncoids and ooids. The characteristics of microfacies are summarized in Table 3.1.

3.5.1 *Microfacies C1 : Oncolitic wackestone and lime mudstone*

Microfacies C1 consists of gray to dark gray, thin to medium wavy and nonparallel beds of oncolitic wackestone and lime mudstone with mudstone partings (Fig. 3.2 A). Oncoids are mainly of Type A with common branching cortices. Bioclasts are rare and consist of algae, foraminifera, ostracods and bivalves. Micritic encrustment is common. Intraparticle porosity is often occluded by micrite. Rare evaporite pseudomorphs occur locally. Dolomites are a minor component and occur more commonly than in Microfacies C2.

Microfacies C1 occurs mainly in the Wiang Sawan and Muang Kham Members at the Phra That Muang Kham temple, Doi Chang, Nopawong quarry and the Phra Thu Pha sections.

Table 3.1 Summary of principal lithological characteristics of Lampang carbonate microfacies

Microfacies	Lithological characteristics	Degree of occur. *	Facies r/ship	Analogy	Interpretation
C1 : Oncolitic wackestone and lime mudstone	Thin-medium & wavy beds, shale partings, type A oncoids with common branching forms, sporadic bioturbation	A	C2, C5	SMF 22(Wilson, 1975)	Back ramp, restricted lagoon, subtidal/ deep ramp
C2 : Oncolitic peloidal packstone	Thin to medium & wavy beds, abundant rounded type A oncoids, matriced by peloids & bioclasts; common bioturbation, micritic envelope & encrustment	A	C1, C3, C10	SMF 22(Wilson, 1975); Aigner, 1985	Back ramp, intermittently agitated lagoon, subtidal
C3 : Peloidal grainstone	Dark gray, consisting of discreted & well sorted peloids, bioclasts mostly of foraminifera, echinoderms	C	C2	SMF 16(Wilson, 1975); Purser, 1973	Back ramp, lagoon
C4 : Peloidal algal packstone	Pure carbonates, massive beds, consisting of irregular shaped peloids, type C oncoids & algal fragmt., rare fauna	A	C5, C6	Persian Gulf (Purser,1973)	Leeward side of shoal or reef, regressive platform
C5 : Skeletal peloidal packs- wackestone	Consisting mainly of skeletal debris with some peloids, common micritic envelope & encrustment	C	C1, C2, C4, C12	SMF 17(Wilson, 1975); Persian Gulf(Purser, 1973)	Leeward side of shoal and lagoon
C6 : Stromatolite	Laterally-linked hemispheroid shape, frequently doming	R	C4	SMF 20(Wilson, 1975)	Intertidal, regressive platform
C7 : Flat pebble packstone	Dark gray, tabular shaped with algal relic, mod.-good orientation, often associated with type A ooids	R	C11	-	Tidal flat, shallow ramp
C8 : Radial-cortex oolitic packstone	Thin- medium beds, lamination, consisting of type B ooids, low diversity of fauna, associated with clastic sequence	R	-	Lagoon ooids(Loreau & Purser, 1973; Strasser, 1986)	Restricted lagoon, tidal flat
C9 : Oncolitic grainstone	Thin, lens with erosional basal contact, consisting of type B oncoids	R	C10, C11	SMF 13(Wilson, 1975)	Channel on shallow ramp
C10 : Dasycladacean grainstone	Dense textured, consisting mainly of dasyclads, slightly oriented, common micritic envelope	R	C2, C9	SMF 18(Wilson, 1975); Wright, 1983	Channel, shallow ramp (landward)
C11 : Concentric - cortex oolitic grainstone	Thick unit, parallel to paleoshoreline, lamination & cross beds, over packing, consisting mainly of type A ooids, broken & diagenetic ooids	C	C2	SMF 15(Wilson, 1975); Persian Gulf(Purser & Evans, 1973)	Winnowed platform, tidal bar, shallow ramp
C12 : Skeletal grainstone	Well sorted bioclasts, mod.- good orientation, common micritic envelope	A	C4, C5, C10	SMF 11(Wilson, 1975); Persian Gulf(Purser, 1973)	Winnowed platform, shallow ramp
C13 : Thin-shelled bivalve wackestone and packstone	Displaying Bouma seq., containing thin shelled bivalves, calcisphere, associated with mudstone seq.	C	T6, T7	Meischner, 1964; SMF 4 (Wilson, 1975); Tucker & Wright, 1990	Slope and basin
C14 : Thin- and parallel bedded lime mudstone	Thin, even & parallel beds	R	T6		Basin

* A = abundant, C = common, R = rare

Fig. 3.2 Photomicrographs of Microfacies C1 to C7.

A) Limestone and thinly interbedded shale (Microfacies C1); Wiang Sawan Member at Nopawong limestone quarry, Mae Moh.

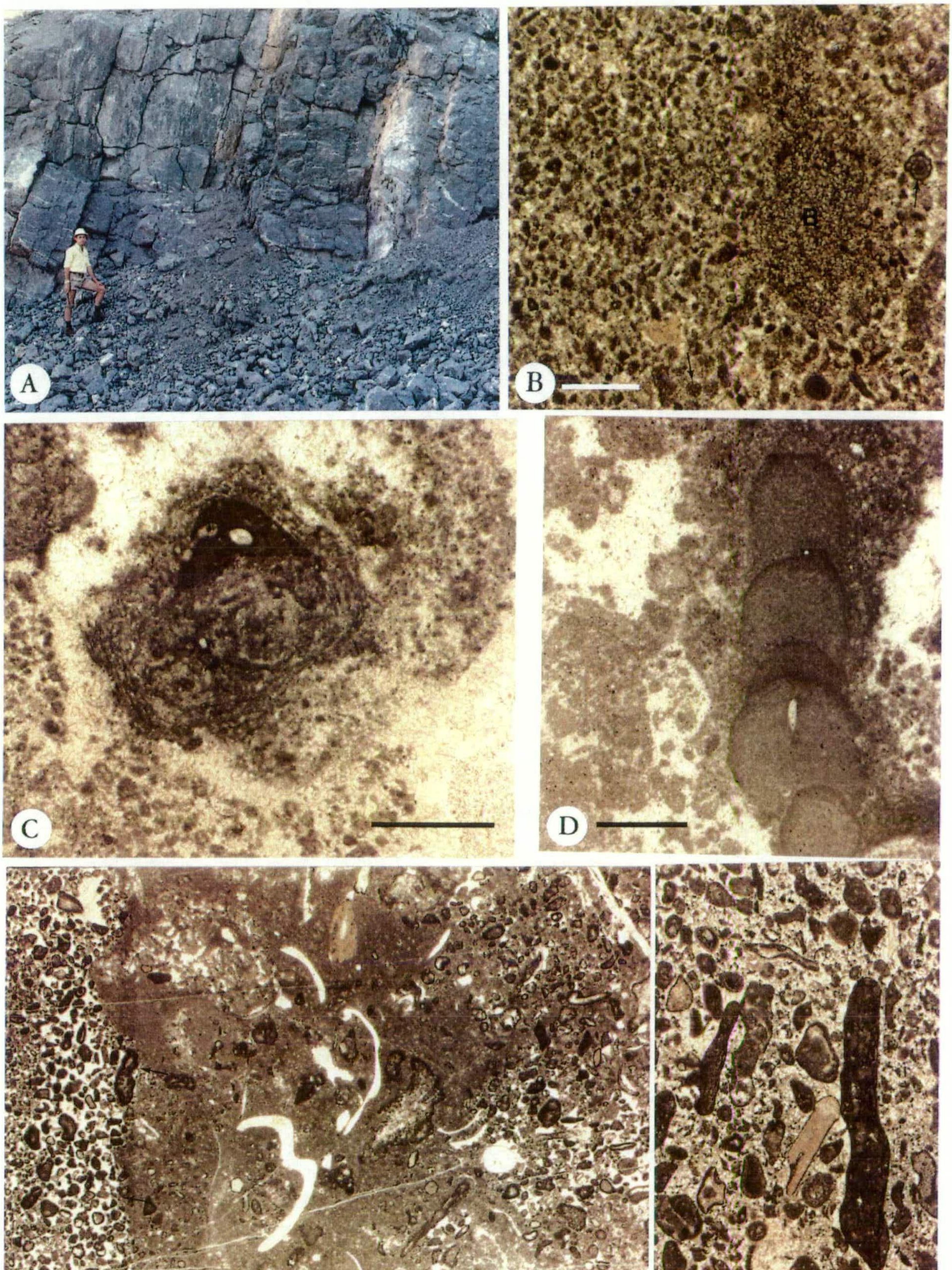
B) Peloidal grainstone (Microfacies C3) consists of discrete peloids with abundant foraminifera (arrow). Boring(B) is filled by ferroan dolomite; sample no SC 32, Huai Muang Member at Phra That Muang Kham temple. Bar scale is 500 microns.

C) Photomicrograph of peloidal algal packstone (Microfacies C4) showing close relationship in their texture between Type C oncoid and peloids; sample no PL 134, Doi Long Formation at Doi Nok. Top to the right. Bar scale is 1 mm.

D) Problematic algae *Tubiphytes* is common in microfacies C4; Doi Long Formation. Bar scale is 1 mm.

E) Deepening-upward sequence, from skeletal grainstone (Microfacies C12) with erosional basal contact (arrow), passing upward to Microfacies C5, the skeletal wackestone (top to the left); sample PL 160, Kang Pla Formation at km 45.5 on the Rong Kwang-Ngao highway. Bar scale is 5 mm.

F) Flat-pebble packstone (Microfacies C7) consists of elongated, tabular intraclasts with commonly algal relics; sample no PL 325, Wiang Sawan Member at km 22+800 m on the Lampang-Denchai highway. Bar scale is 2 mm.


A
B
B
C
D
E
F

Interpretation : The occurrence of branching forms on the cortices of the oncoids in Microfacies C1, in addition to the micritic matrix, suggests low-energy conditions, possibly a lagoonal environment. This interpretation is supported by the occurrence of rare evaporites. This microfacies is analogous to the micrite with large oncoids microfacies, the SMF 22 of Wilson (1975) which typically occurs in shallow water back-shoal environments.

3.5.2 *Microfacies C2 : Oncolitic peloidal packstone*

This microfacies is characterized by thin-to medium and wavy bedded, dark gray packstone, consisting mainly of Type A oncoids with subordinate peloids and bioclasts (Fig. 3.1 A). Branching cortices in the oncoids are less common than Microfacies C1. Sparry calcite dominates over micrite. Borings are common in the cortices of oncoids. Geopetal fabrics are present. Peloids are mainly discrete grains, rounded, and subspherical to irregular in shape, and range in size from 40 to 100 μm. Clotted structures are rare. Bioclasts consist mostly of algae (e.g., dasyclads), bivalves, echinoderms, gastropods, ostracods and foraminifera. Bioclasts also serve as nuclei for the growth of oncoids. Micritic envelope and micritic encrustment are common. Dolomites are minor components.

This microfacies is often associated with oncolitic wackestone (C1) and peloidal grainstone (C3). It occurs mainly in the Muang Kham and Wiang Sawan Members at the Phra That Muang Kham temple and Phra Thu Pha sections.

Interpretation : Microfacies C2 is interpreted as having accumulated in restricted shoal to back ramp environment because: 1) Microfacies C2 is cemented by mainly sparry calcite indicating formation under intermittently agitated water conditions. A lack of evidence of subaerial exposure implies deposition in a relatively active subtidal zone, 2) in modern settings (Loreau and Purser, 1973; Wilson and Jordan, 1983) and in ancient settings (Aigner, 1985; Chatellier, 1988) oncolites similar to Microfacies C2 develop in shallow ramp to back ramp environments, 3) Wilson (1975) noted that oncoids with a sandy matrix may have been formed and deposited in channels or near shoals, 4) it often grades up to peloidal grainstone microfacies deposited in a restricted marine shoal environment, 5) abundance of algae and oncoids and the fauna assemblages suggest formation in a shallow marine environment within a photic zone, and 6) oncoids forming in marine lagoons are irregular shaped and most are bigger than 1 cm in diameter (Aigner,1985; Chatellier, 1988), whereas those forming in agitated and shoreface environments have a dense fabric, good sphericity and are less than 1 cm in diameter (Bishop, 1968)

3.5.3 *Microfacies C3 : Peloidal grainstone*

This microfacies consists of gray to dark gray, discontinuous, wavy, thin-bedded peloidal grainstone, often occurring as part of shallowing-upward sequences such as those grading up to oolitic grainstone (C11) and as intercalated beds in oncolite sequences (C2). Its appearance is similar to lime mudstone, due to the very small size of peloids. However, the peloids are clearly distinguishable in weathered surface outcrops.

Microscopically, this microfacies consists mainly of peloids (constituting up to 50% of the thin section) with low faunal diversity and common foraminifera. Radial ooids (100-150 μm in diameter) are a minor component (Fig. 3.2 B). Peloids are discrete grains, rounded, well sorted and ellipsoidal to spherical in shape, and range in size from 40 to 100 μm. They are often cemented by equant cement and generally show weak to moderate grain orientation. Bioturbation is common.

Peloidal grainstone microfacies within the measured section is mainly restricted to the Wiang Sawan and Muang Kham Members in the Phra That Muang Kham and the Phra Thu Pha sections. It also occurs in the Kang Pla Formation in the reconnaissance localities at Doi Pha Lak Mun and Ban Song Sop.

Interpretation : Microfacies C3 is interpreted to have been deposited in an agitated lagoon and subtidal environments because: **1**) of the modern occurrence, a similar microfacies on the Trucial Coast of the Persian Gulf, where carbonate pellet sands rich in imperforate foraminifera, form mainly in restricted environments and in the intertidal and subtidal areas in the leeward side of barrier islands (Purser, 1973; Wagner and van der Togt, 1973). Lack of subaerial features in this microfacies suggests subtidal environments rather than intertidal, **2**) the lack of micritic matrices in the interparticle pores suggests agitated waters, **3**) it is usually associated with oolite and oncolite which are interpreted as having been deposited in shoaling areas, and **4**) it is analogous to SMF 16, the restricted marine shoal peloidal grainstone of Wilson (1975).

3.5.4 *Microfacies C4 : Peloidal algal packstones*

Peloidal algal packstone microfacies is light gray and massively bedded. Beds are hardly distinguishable, possibly partly due to recrystallization. In hand specimen, the rock has the appearance of lime mudstone or wackestone with a scattering of light brown dolomitized patches. Microfacies C4 consists mainly of peloids, algal debris and Type C oncoids (Figs. 3.2 C, D). Peloids generally predominate over skeletal grains. They are rounded, irregular in shape and moderately to poorly sorted, and range in size from 100 to 600 µm (mode of about 100 to 200 µm). Peloids are closely associated with algae and oncoids (Fig. 3.2 C). Algae are composed mostly of blue-green (cyanophytic) and green algal (chlorophytic) fragments with some *Tubiphytes* (Fig. 3.2 D). Algal layers and algal tubes are common. Fauna is scarce and of low taxonomic diversity consisting of echinoderms and minor foraminifera and bivalves. This microfacies is often associated with skeletal peloidal packstone (C5) and stromatolites (C6).

This microfacies is dominant in the Doi Long Formation and has been found in all five sections (Fig. 2.7) measured along a depositional strike of about 30 km.

Interpretation : Microfacies C4 is interpreted as having been deposited in the leeward side of a shoaling area. The modern occurrence of patch reefs in the Persian Gulf (Purser, 1973) shows that skeletal debris and peloids are common on the leeward side of the reef. Similarly, algal debris of Microfacies C4 was probably transported by wave action to the leeward side. Grain size of the skeletal debris decreases towards the lagoon whereas mud contents increase. Interpretation of this microfacies is hampered by strong recrystallization. The residue from dissolved limestone for conodonts indicates that this microfacies is clean carbonate. This suggests that it was deposited in clear marine water far from clastic sources. The light coloration suggests a considerable degree of oxidation.

The origin of peloids has been much discussed with five likely explanations (Tucker and Wright, 1990); an algal origin, a replacement texture, detrital sediment, product of pelletizing organism, and *in situ* precipitation. Variable morphology of peloids (Fig. 3.2 C), in addition to poor sorting, scarcity of fauna and bioturbation, are all suggestive of algal origin rather than fecal formation (Flügel, 1982, p 133). The bacterially- precipitated peloids of Reid (1987) are similar in their morphologies to this microfacies but they are well sorted, sometimes graded and often cemented by more than one rim of bladed cements.

3.5.5 *Microfacies C5 : Skeletal peloidal packstone-wackestone*

This microfacies consists mainly of skeletal debris with subordinate peloids. Skeletal grains, commonly with micritic encrustment and envelopes, consist mostly of algal debris (mostly green and blue-green algae), bivalves, echinoderms and foraminifera with subordinate ostracods and gastropods (Fig. 3.2 E). They show weak orientation and moderate to poor sorting. Marine cement is present locally and may be overlain by internal sediment. Peloids are often discrete grains, rounded, spherical to ellipsoidal, moderately to well sorted, and range in size from 40 to 150 μm. Intraparticle porosity is occluded by either micrite or sparry calcite.

In outcrop, Microfacies C5 is light gray, massively bedded and closely associated with peloidal algal packstone (Microfacies C4), or dark gray, thin- and wavy-bedded and associated with oncolites (Microfacies C1& C2). With regard to the five measured sections of Doi Long Formation (Fig. 2.7), Microfacies C5 is common at both northern and southern ends of the limestone trend.

Interpretation : Microfacies C5 is interpreted as having formed in either windward or leeward of the shallow ramp. This interpretation bears strong similarity to modern occurrences in the Persian Gulf, Malta, and Tunisia (Purser, 1973; Buxton and Pedley, 1989). Lack of grain orientation reflects low current energy. Microfacies C5 is similar to, restricted marine shoal, SMF 17 of Wilson(1975).

3.5.6 *Microfacies C6 : Stromatolite*

The stromatolitic microfacies is dark gray, laminated (up to 5 mm thick), wavy- and parallel-bedded, commonly with cauliflower structures. In thin section, it is characterized by interlaminated filaments (about 2 mm) and micrite (about 1.6 mm). The filaments may be highly dissolved displaying protuberant and crinkle structures, and in some places, micritic threads. Replacement dolomites, weathering yellowish-brown, occur commonly along the laminar planes.

Stromatolites are not common in the Lampang carbonates. They occur locally in Doi Huai Long of the Doi Long area ~~Formation~~.

Interpretation : Modern and ancient stromatolites have been observed from both shallow and deep marine environments (Purser and Evans, 1973; Wongwanich, 1990). The occurrence of Microfacies C5 which is associated with shallow marine microfacies (C4) suggests a shallow marine origin.

3.5.7 *Microfacies C7 : Flat-pebble packstone*

Flat pebbles are characterized by tabular shape and gray color, are well rounded and often contain algal relics (Fig. 3.2 F). This microfacies also contains Type A ooids and skeletal grains (gastropods, bivalves, algae and echinoderms) and displays moderate to good orientation of allochems. The flat-pebble packstone microfacies is rare, occurring only in the Wiang Sawan Member (Fig. 2.4 C).

Interpretation : The intertidal zone of the Trucial Coast is dominated by a veneer of microbial mats in the upper part (Tucker and Wright, 1990). Desiccation and break-up of the mats are common in this area and give rise to intraclasts or flat pebbles. These flat pebbles were swept away and deposited nearby. Microfacies C7 is interpreted by analogy with the Trucial Coast as forming in an intertidal to shallow subtidal environment.

3.5.8 *Microfacies C8 : Radial- cortex oolitic packstone*

Microfacies C8 is laminated to thin-bedded, moderately to poorly sorted oolitic packstone with rare grainstone and often contains a low diversity fauna (Figs. 3.1 E and 3.3 A). It typically occurs as thin units (normally less than 60 cm) with poor lateral continuity, often displaying a shallowing-upward sequence passing from wackestone to oolite, and is closely associated with shales and sandstones of tidal origin. In thin section, it consists mainly of Type B ooids with minor bioclasts, composite grains and oncoids. Where ooids are small (< 200 μm), they have good sorting. Peloids and bioclasts serve as ooid nuclei. Bioclasts consist mainly of *Girvanella* lumps, foraminifera, echinoderms and bivalves. Composite grains comprise mainly ooids and some have developed into oncoids.

This microfacies is restricted to the Chang Garb Member, at Doi Chang and at Phra That Muang Kham temple sections.

Interpretation : Abundant Type B ooids and the low-diversity fauna in Microfacies C8, in addition to lack of broken ooids and truncated grains within the composite grains indicate that Microfacies C8 formed in restricted areas or lagoons. Rare cross-bedding indicates occasionally agitated waters. Modern oolitic sediments similar to Microfacies C8 are forming in protected lagoons in the Persian Gulf (Loreau and Purser, 1973).

3.5.9 *Microfacies C9 : Oncolitic grainstone*

Oncolitic grainstone microfacies occurs as thin and non-parallel beds or lenses, displaying moderate orientation of the allochems and often showing erosional basal contacts. It consists mainly of Type B oncoids (mostly less than 1 cm in diameter) and minor Type A ooids with a matrix of peloids and bioclasts. Micritic envelopes are common. This microfacies is closely associated with oolitic grainstone (C11) and dasycladacean grainstone (C10).

Fig. 3.3 Photographs of Microfacies C8 to C14.

A) Oolitic packstone (Microfacies C8) consisting mainly of Type B ooids with abundant foraminifera; sample no C9, Chang Garb Member at Doi Chang. Bar scale is 100 microns.

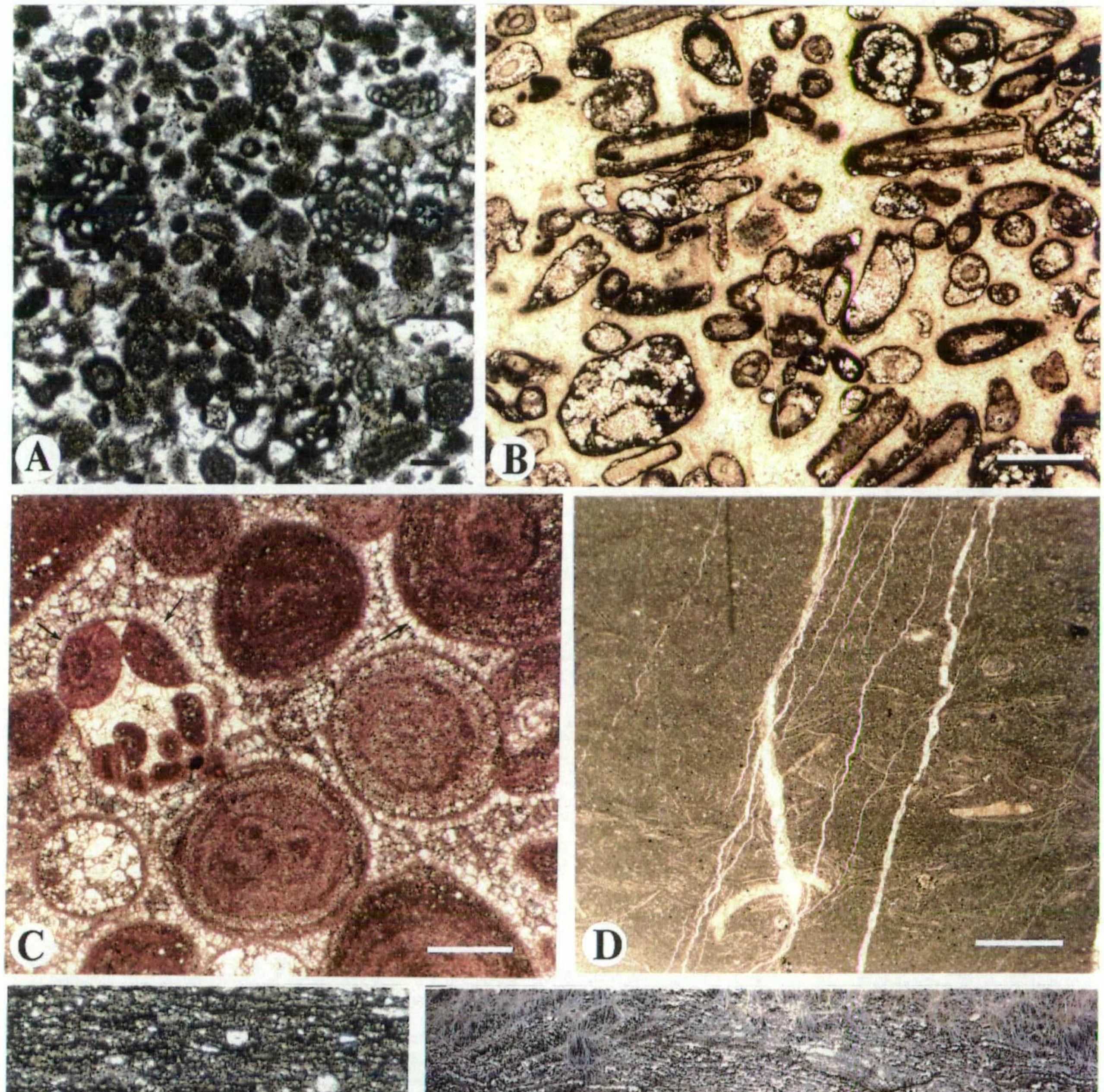
B) Dasycladacean grainstone (Microfacies C10) with marine cement (light brown); sample no PL 23, Wiang Sawan Member at Phra That Muang Kham temple. Bar scale is 2 mm.

C) Oolitic grainstone (Microfacies C11) with clear isopachous meteoric cement (arrow) which formed after the broken ooids (left); sample no PL 53, Wiang Sawan Member at Phra That Muang Kham temple. Bar scale is 500 microns.

D) Thin-shelled bivalves of Microfacies C14; sample no PL 358, Huai Muang Member at Huai Muang. Bar scale is 3 mm.

E) Sheared calcisphere of Microfacies C14; sample no SC78; Huai Chan Member at Huai Chan. Bar scale is 200 microns.

F) Thin- even- and parallel-bedded limestone and mudstone of Microfacies C13. Note good lateral continuity of beds; Hong Hoi Formation at km 577, Phaholyothin highway.


A
B
C
D
E
F

This microfacies occurs locally in Wiang Sawan and Muang Kham Members at Phra That Muang Kham temple and at Phra Thu Pha sections.

Interpretation : Type B oncoids indicate deposition in agitated waters (see section 3.3). Microfacies C9 may be equivalent to SMF 13, the oncolitic grainstone forming in a moderately high energy, shoal environment (Wilson, 1975), and the bar environment of Rao and Naqvi (1981). Its lensoidal geometry, often displaying erosional basal contacts, points to channels on shoal and bar environments.

3.5.10 *Microfacies C10 : Dasycladacean grainstone*

Microfacies C10 consists mainly of dasyclad fragments (about 1-2 mm in width and 5 mm in length) and other minor fossils such as foraminifera, gastropods, echinoderms, bivalves, and intraclasts (Figs. 2.5 D and 3.3 B). It is usually dense-textured, medium to thin- and wavy bedded, and has marine acicular fibrous cement. Dasycladacean grainstone is commonly the uppermost microfacies of shallowing-upward sequences that begin with oncolitic packstone and wackestone and grade up to dasycladacean grainstone. Most fossils display micritic envelopes. Solution porosity, within the dasyclads and other fauna, is common and is filled by clear sparry equant calcite. The allochems are moderately sorted, rounded, slightly oriented, and cemented by an initial generation of marine cement, as are the intraparticle pores. Dolomites are rare.

This microfacies is restricted to the Wiang Sawan Member of the Pha Kan Formation. It is observed only at the Phra That Muang Kham temple section in which at least four shallowing-upward sequences were observed.

Interpretation : This microfacies appears to have been deposited in the channel of a restricted marine shoal (landward) environment, as suggested by: 1) its occurrence on top of the shallowing-upward sequence, 2) the abundance of shallow marine dasyclad fragments (Wright, 1983). It is noted by Wilson and Jordan (1983) and Flügel (1982) that dasycladacean algae are relatively tolerant to salinity variation and are commonly found in shallow marine environments of less than 5 m depth, 3) the presence of marine isopachous acicular fibrous cement that requires agitated sea water conditions (though not agitated enough to produce strong orientation of the grains), 4) its geometry of wavy, non-parallel and discontinuous channelized beds, 5) the common modern occurrence in the Bahama Bank of calcareous algae in the protected back-reef lagoonal area (Tucker and Wright, 1990), and the similarity to 6) SMF 18, the dasycladacean grainstone of Wilson (1975) which forms in a restricted marine shoal environment, commonly on a tidal bar or in the channel of a lagoon.

3.5.11 *Microfacies C11 : Concentric-cortex oolitic grainstone*

In outcrop, this microfacies occurs as a thick oolitic unit. It often displays cross-bedding and occurs at the top of a shallowing-upward sequence which passes from oncolite at the base to oolite. Microfacies C11 consists mainly of ooids with minor bioclasts, oncoids and peloids. Ooids are mostly Type A ooids and diagenetic ooids such as blocky ooids (Chow and James, 1987) and in situ replacement ooids (Tucker, 1984) with some broken ooids and composite grains. They are moderately to poorly sorted, cemented by clear equant isopachous calcite. They often feature an overpacked fabric (Figs. 3.1 D and 3.3 C) and intercalated peloid layers.

This microfacies occurs mainly in the upper part of the Wiang Sawan Member at the Phra That Muang Kham temple and partly in Doi Long Formation at the Doi Nok area. The oolites in the former area appear to have been deposited under relatively stronger current energy as suggested by the ooid assemblages (broken ooids, composite grains with grains truncated on the edges) and more abundant cross-bedding.

Interpretation : This microfacies is interpreted as having been deposited in the tidal bar of a shoaling area far away from terrigenous influx. This interpretation is supported by: **1**) its occurrence parallel to the paleoshoreline as suggested by its elongate geometry and paleocurrent direction, **2**) the predominance of Type A ooids and their occurrence at the top of shallowing-upward sequences, **3**) common cross-stratifications, suggesting high water energies above fair weather wave base, **4**) the presence of broken ooids and composite grains which reflect wave and current reworking (Tucker, 1984), and **5**) its similarity to SMF 15, ooids shoal facies of Wilson (1975) which is typically deposited in agitated tidal bar environment. Microfacies C11 is also similar to modern occurrence in the Persian Gulf (Purser and Evans, 1973), Triassic Upper Muschelkalk, Germany (Aigner, 1985), and to the Upper Cambrian Nolichucky Formation, USA (Markello and Read, 1981); however storm sedimentation which is common in the aforementioned occurrences, is here rare to absent.

3.5.12 *Microfacies C12 : Skeletal grainstone*

Microfacies C12 forms part of both shallowing-upward and deepening-upward sequences. Shallowing-upward sequences change from one of lime mudstone, wackestone, peloidal algal packstone, or skeletal packstone up to skeletal grainstone. Deepening-upward sequences grades from skeletal grainstone, with a sharp basal contact, upward to wackestone (Fig. 3.2 E). This microfacies is closely related to peloidal algal wackestone (C4), skeletal peloidal packstone (C5) and dasycladacean grainstone (C10). Burrows occur locally. In thin section, the grainstone consists mainly of bioclasts and subordinate ooids and intraclasts. It shows moderate to strong orientation, and intra- and interparticle pores with a first generation of marine isopachous cement. Bioclasts are all rounded, disarticulated and fragmented, and consist mainly of algae (such as dasyclads and *Girvanella*), foraminifera, echinoderms and ostracods, with common micritic envelopes. Ooids are mainly Type A with peloids or bioclasts serving as nuclei. Intraclasts, particularly those having elongated grain, often contain relic algae. Replacement dolomite is a minor component.

This microfacies occurs locally in the Cave Temple Member (at Doi Pha Khan and at Doi Chang), the Wiang Sawan Member (at Phra That Muang Kham temple and at km 22.8 on the Lampang-Denchai highway) and in the Doi Long Formation, and it is common in the Kang Pla Formation (at km 45.6 on the Rong Kwang-Ngao highway).

Interpretation : The skeletal grainstone microfacies is interpreted as having formed in agitated shallow ramp environments because: 1) good to moderate orientations of the allochems imply an agitated water environment, 2) isopachous marine cement points to syndeposition under phreatic and moving water conditions, 3) micritization of grain margins by endolithic algae, fungi or bacteria are common in shallow marine environments, 4) in most modern settings, skeletal grainstones dominate in shoreface- foreshore- backshore environments (Tucker and Wright, 1990), and 5) it is similar to the shallow ramp bioclastic sands of the Persian Gulf and may be analogous to the SMF 11, the bioclastic grainstone microfacies of Wilson (1975).

3.5.13 *Microfacies C13 : Thin-shelled bivalve wackestone and packstone*

Microfacies C13 consists of laminated to thin-and non-parallel bedded limestone that is intercalated with a mudstone sequence. Components of the Bouma sequence, particularly Ta (graded with rare flute structures), Tb and Td are common in the limestone. Microfacies C13 is often associated with mudstones of Facies T6 and disturbed beds of Facies T7 (for details see Chapter 4).

Microscopically, this microfacies consists of thin-shelled bivalves (Fig. 3.3 D), calcispheres (Fig. 3.3 E) and ostracods in wackestone to packstone. The fossil proportions are variable. At one extreme, it consists mainly of calcispheres, and at the other, mostly of thin-shelled bivalves. The thin-shelled bivalves, like the ostracods, are light brown in plane-polarized light and are commonly cemented by clear fibrous calcite. Their sizes are 5 to 15 µm thick and up to 1600 µm in length but generally they are broken to fragments less than 500 µm long. They mostly lie parallel to the bedding plane but oblique orientations also occur. The calcispheres consist of walled and unwalled types ranging in size up to 200 µm but normally less than 100 µm. The ostracods are generally smaller than 1 mm in size and the valves may be articulated.

This microfacies occurs mainly in the Huai Chan Member at the Huai Chan section (Fig. 2.10 C), and represents less than 10 % of the sections measured through the Huai Muang and the Phu Tap Members (Figs. 2.6 A, 2.10 and 2.12).

Interpretation : Microfacies C13 is interpreted as slope to basinal sedimentation because: **1**) the occurrence of thin-shelled bivalves are regarded as pelagic by many authors (Wilson, 1975; Flügel, 1982; and Tucker and Wright, 1990), and are significant elements of Triassic and Jurassic pelagic facies, **2**) the occurrence of Bouma Tabcd (Fig. 2.11 D) implies deposition from suspension of low-concentration turbidity current which was decreasing in its concentration; the lag deposits, in addition to associated slump structures, suggest a steep slope and a proximity to source; lamination also implies a quiet depositional environment and setting from suspension, **3**) reworked sediments such as the type of fauna and eroded allochems are common in this microfacies, **4**) limestone turbidites are well documented from various deep sea slope locations such in the Bahamas and the Fiji Islands (Meischner, 1964; Flügel, 1982; McILreath and James, 1984), **5**) it is similar to the allodapic limestone of Meischner (1964); allodapic limestone is partly derived from shallow water carbonates bordering the turbidite basin, and is transported by gravity flow processes into deep marine environments. The feeder system for occurrence of limestone turbidites is suggested by Tucker and Wright (1990, p 273), based on lack of modern and rarity of ancient carbonate fans, that the sediments were supplied to the slope by multiple-point rather than a single- point sources.

3.5.14 *Microfacies C14: Thin- and parallel bedded lime mudstone*

In outcrop, Microfacies C14 is thin- and parallel bedded (5-10 cm thick) lime mudstone that is interbedded with mudstone (Fig. 3.3 F). Limestone to mudstone ratio is one or less. Microscopically, the microfacies consists mainly of micrite with rare skeletal grains.

Only one exposure of Microfacies C14 was observed and is located outside the main study area at km 577 on the Phaholyothin highway. It has been mapped as the Hong Hoi Formation (Piyasin, 1972). No relationship to other microfacies has been observed except that it is closely associated with the mudstones of the basinal facies (Facies T6, for details see Chapter 4).

Interpretation : The occurrence of thin- and parallel bedded lime mudstone and interbedded mudstone which lack features suggestive of shallow water deposition, such as algae and benthic fauna, suggest that this microfacies may have formed under relatively quiet conditions, below fair weather wave base or in a basinal environment.

3.6 Depositional environments of the Lampang carbonates

According to Tucker and Wright (1990), carbonate platforms can be subdivided into five broad categories as follows: rimmed shelf, ramp, epeiric, isolated, and drowned platforms.

The rimmed shelf and epeiric platforms depositional models are not appropriate to the Lampang carbonates. In the first case, the Lampang carbonates lack a elongate barrier-reef, fore-reef deposits and a marked break in slope that are expected of a rimmed shelf. In the second case, they are too small to qualify as an epeiric platform. An epeiric platform is very extensive (100-10,000 km wide), quite flat, cratonic areas covered by a shallow sea (Tucker and Wright, 1990). The isolated platform model is also excluded because of a lack evidence of deep water sediments surrounding the Lampang carbonate platform.

Three distinct limestone depositional models can be recognized in the Lampang Group as follows:

1. Ramp platform, represented by the Pha Kan Formation, Kang Pla Formation. The Huai Chan Member is considered as the basinal part in the ramp model.

2. Drowned ramp platform, represented by the Cave Temple Member and the Kang Pla Formation.

3. Regressive platform, represented by the Doi Long Formation.

3.6.1 Ramp platform of the Lampang carbonates

By definition, a carbonate ramp (Ahr, 1973) is a shallow, gently sloping platform (slope typically less than 1°) with a high energy grainstone belt situated on the landward part of the ramp. In contrast, the high energy grainstone belt of a rimmed shelf is developed on the basinward edge of the shelf. Aigner (1985) also used the facies distribution pattern parallel to the coastline as a criterion for identification of carbonate ramps.

Interpretation of ramp platform environments for the Pha Kan and Kang Pla Formations is based on a lack of continuous barrier reef, fore-reef deposits which, in turn, indicates the lack of a marked break in slope and their relatively limited distribution. In addition, the Pha Kan Formation displays high-energy sediments in a landward position (Microfacies C9 through C12 of Fig. 3.4). The wide distribution of oncolites in the Wiang Sawan Member (Fig. 2.4), in addition to a general lack of turbidites and slump structures, implies that the carbonate ramp paleoslope was gentle. Lampang carbonates may have been deposited on a ramp similar to the homoclinal ramp of Read (1982). Carbonate ramps elsewhere, for example, the Trucial Coast of the Persian Gulf (Purser, 1973), Upper Cambrian Nolichucky Formation of Virginia (Markello and Read, 1981), the middle Triassic Upper Muschelkalk Formation of Germany (Aigner, 1985), and in the Safety Valve of South Florida (Aigner, 1985), all contain significant storm deposits. This is not the case in the Lampang Group. All the examples mentioned above are ramps wider than 100 km which make them more susceptible to the effects of waves and storms. The Lampang carbonates, based on modern outcrop patterns, may have been formed in narrow, elongate and possibly protected depositional basins. The ramp facies consists of four main depositional environments: **1**) back ramp or lagoon, **2**) shallow ramp or shoal, **3**) deep ramp, and **4**) slope and basin (Fig. 3.4).

Back ramp or lagoon environment

Lagoons are generally the sites for accumulation of fine-grained sediments often with a restricted fauna. In the modern lagoons of the Persian Gulf, skeletal peloidal sands dominate in the moderately circulated areas while lime mud and pelletal mud are deposited in the most protected areas (Tucker and Wright, 1990).

A lagoonal environment is represented by microfacies assemblages of oncolitic wackestone and lime mudstone (Microfacies C1), oncolitic packstone (C2), peloidal grainstone (C3) and skeletal peloidal packstone- wackestone (C5). These microfacies commonly form in the lower part of shallowing-upward sequences, and pass upward to oolitic and dasycladacean grainstones of the shallow ramp environment (Fig. 3.5 A2). The oncolitic wackestone and lime mudstone microfacies (C1) and peloidal grainstone microfacies (C3) contain low diversity fauna, thus they may have accumulated in the central part of the lagoon while the Microfacies C2, and C5 possibly formed in more circulated areas. Oncolites elsewhere are observed in back ramp environments (Aigner, 1985; Chatellier, 1988). Sediments of high-energy condition such as dasycladacean grainstone (Microfacies C10) and skeletal grainstone (Microfacies C12) also can be accumulated in the lagoonal flank due to washover processes during high wave action, and they normally form tail morphology towards the lagoon. Lack of significant evaporites in the Lampang carbonates implies generally near normal salinity which in turn indicates a connection between a lagoon and the open sea. Stromatolites (Microfacies C6) may have formed in tidal flats similar to modern occurrences in the Persian Gulf and the Great Bahama Banks. The oolitic packstone (C8) often contains a restricted fauna and is associated with peritidal sandstone and mudstone. Thus, it may have formed in restricted areas on tidal flats.

Lagoonal sediments dominate in the Wiang Sawan and the Muang Kham Members at Phra That Muang Kham temple, Doi Chang and the Phra Thu Pha areas.

Shallow ramp or shoal environment

Shallow ramps are the areas subjected to both wave and current action. Thus, sedimentary structures resulting from wave and current actions are common. The shallow ramp environment is dominated by either oolitic grainstone (C11) or skeletal grainstone (C12) belts with minor skeletal packstone (C5), oncolitic grainstone (C9) and dasycladacean grainstone (C10). Grainstones simply imply high energy conditions where all lime mud is winnowed away. The deepening-upward sequence (Fig. 3.2 E), changing from skeletal grainstone (C12) up to wackestone, suggests a relative sea-level rise that was greater than sedimentation rate. This probably indicates a generally transgressive sequence. The vertical sequence showing grain size decrease upwards (Fig. 3.5 A3), from lenticular oncolitic grainstone (C9) to dasycladacean grainstone (C10), possibly implies deposition from a waning flow in a tidal creek on a shallow ramp; a similar situation occurs commonly in siliciclastic deposits. Skeletal packstone-wackestone microfacies (C5) may have formed in both foreshore and backshore environments. Sedimentation in the backshore setting is caused by wave or other high energy episodes transporting skeletal fragments from foreshore through backshore and lagoon. Flat-pebble packstone (C7) possibly formed on the leeward side of a shallow ramp, close to the tidal flats from where it was derived. Moderate orientation of the flat pebbles suggests a moderate current activity. The shallow ramp area may have been dissected by channels which provided a connection between the lagoon and the open sea. Buildups failed to develop possibly because of high rates of fine clastic influx or rapid downwarping that exceeded biological carbonate accumulation, as suggested by Read (1980, p 595).

In the measured sections, sediments of shallow ramp environment are not abundant. They occur at Phra That Muang Kham temple and at km 45.5 on the Rong Kwang-Ngao highway.

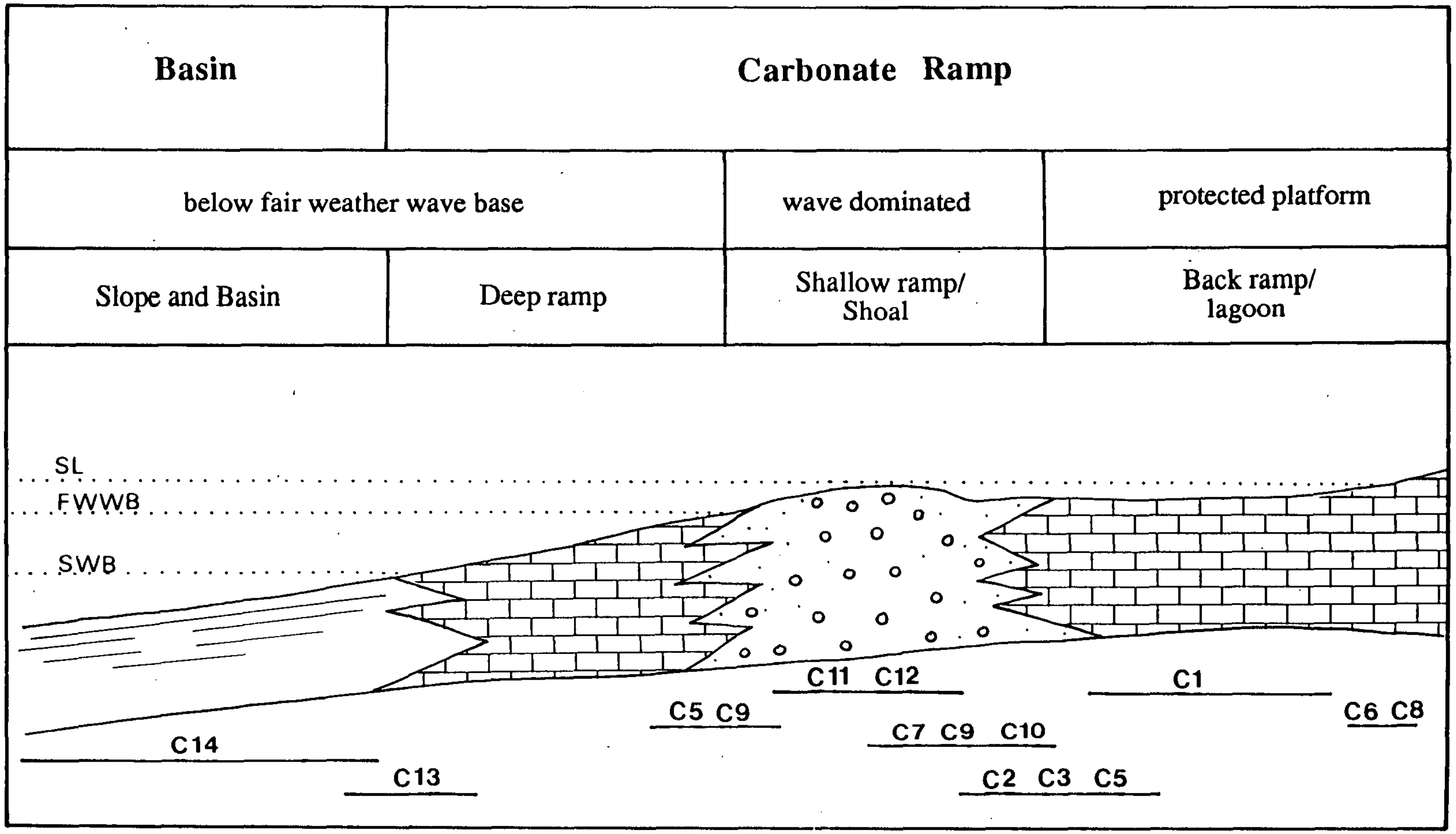


Fig. 3.4 Depositional facies of the carbonate ramp of the Lampang Group (depositional model modified from Read, 1980; Aigner, 1985).

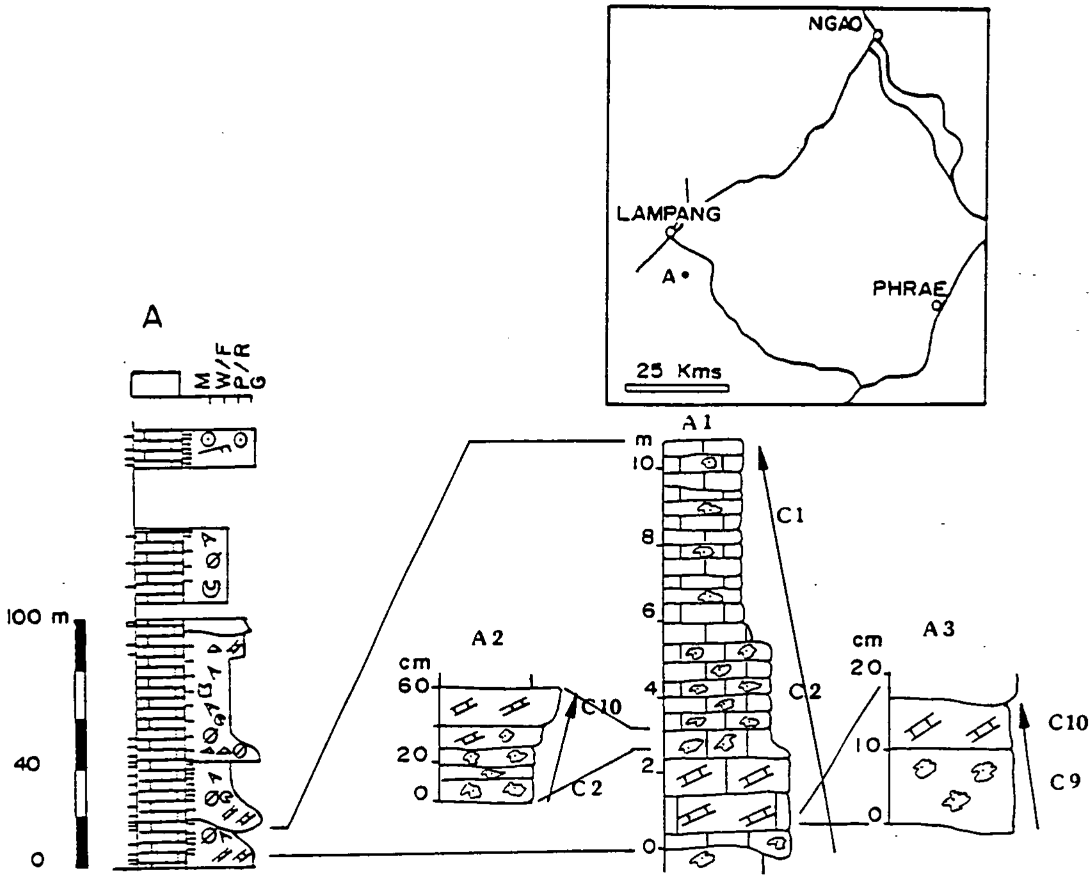


Fig. 3.5 A-1) Deepening-upward sequence, from oncolitic grainstone (C9) and dasycladacean grainstone (C10) passing upward to oncolitic packstone (C2) and lime mudstone (C1). A-2) Shallowing upward sequence, from oncolitic packstone grading upward to microfacies C10. A-3) Decrease in grain size from oncolitic grainstone to dasycladacean grainstone, possibly implying deposition from waning flow in a channel environment.

Deep ramp environment

Deep ramp sediments are deposited below fair weather wave base. Elsewhere, they consist of wackestone and lime mudstone and feature nodular bedding, whole fossils and a diverse open marine fauna (Markello and Read, 1981; Aigner, 1985; Tucker and Wright, 1990). Nodular limestones occur locally in the Lampang Group (Fig. 2.11 B). With regard to carbonate provenance, limestone turbidites may have been deposited close to their sources, the carbonate platform. Thus, carbonate turbidites (C13) may have formed in a deep ramp environment. Deepening -upward sequences were observed in many places in the Lampang carbonates. The occurrence of wackestone or lime mudstone at the top of these sequences (Fig. 3.2 E), according to the Walther's Law, may represent deposition in deep ramp. Less abundance of allodapic limestone in the Lampang Group may be due to the fact that the sea-level was generally low during Triassic Period.

Slope and basinal environments

The slope and basinal sediments are represented by the thin-shelled bivalve wackestone microfacies (C13), and thin- and parallel bedded lime mudstone microfacies (C14). This interpretation is based on their lithologies, sedimentary structures such as parallel beds and lack of features indicative of shallow water deposition, and is closely associated with basinal facies of Facies T6 (for details see Chapter 4). Parallel and even beds suggest that the paleogeographical slope was gentle.

3.6.2 Regressive and drowned ramp platforms of the Lampang carbonates

Pronounced vertical regressive sequences from the clastic turbidites of the Hong Hoi Formation passing upward to platform carbonates of the Doi Long Formation and red beds of the Pha Daeng Formation, indicate significant relative sea-level fall. Sea level falls on a carbonate platform result in subaerial hiatus, karst topography, and widespread unconformities (Kendall and Schlager, 1981). An unconformity occurring on top of the Doi Long Formation is represented by limestone-clast conglomerate. There are two factors that need to be considered when attempting explanation for the termination of carbonate production at the end of the Doi Long Formation: (1) whether it was caused by continual uplifts of the carbonate platform to above sea-level or (2) whether there was a significant influx of clastic sediments. Evidence from the limestone-clast conglomerate, lying immediately above the Doi Long Formation, that features debris flow sedimentation and that lacks features suggestive of beach gravel (for details see Chapter 5), points to the latter situation. This interpretation is supported by a lack of evaporites occurring in the lagoonal environment which is common in the former situation (Kendall and Schlager, 1981). The limestone-clast conglomerate initially formed in a shallow marine environment distant from siliciclastic sources. The Doi Long Formation, based on current exposure, has a limited distribution occurring only in the "Tha Si Syncline" area. Elsewhere, at Tha Lai Nok temple of Ngao District, the effect of a sea-level fall is represented by an upward change from gray mudstone facies (Hong Hoi Fm) to red mudstone facies (Pha Daeng Fm).

Drowned platforms are either ramps, rimmed shelves, isolated or epeiric platforms that have been subjected to a rapid relative sea-level rise therefore deeper-water facies are deposited over the shallow-water carbonates. To drown a carbonate platform requires greater rate of sea-level rise than rate of carbonate production. The pronounced vertical facies change, from platform carbonate (Pha Kan and Kang Pla Formations) to clastic turbidites (Hong Hoi and Wang Chin Formations, respectively) indicates a significant increase in the amount of clastic material being deposited and a relative sea-level rise. Rapid relative sea-level rise can be caused by fault-induced subsidence, thermal subsidence resulting from a cessation of volcanic activity, glacio-eustatic sea-level rise, or by a drastic reduction in carbonate production due to some environmental stress (Kendall and Schlager, 1981; Tucker and Wright, 1990). The thermal subsidence usually covers a wide area, unlike the Lampang depositional basin which is believed to have been a narrow and elongate basin. The sea-level curve during the Triassic Period, on the other hand, is generally low (Haq et al., 1988). The causes of the relative sea-level rise, therefore is possibly caused by fault-induced subsidence. Occurrence of structureless conglomerate or olistostrome, at Mae Chang Dam canal in which the largest clasts consist mainly of limestones presumably derived from the underlying Pha Kan Formation, supports this interpretation.

Lithologically, the drowned ramp and regressive platforms consist mainly of light gray "pure" carbonates indicating they may have been formed in oxidizing conditions, distant from siliciclastic influx. The platforms may have been surrounded by shallow seas as suggested by the lack of any significant reefal facies. Hydrodynamic processes on a pure carbonate platform having either a deepening- or shallowing-upward trend may be similar. Modern occurrences of patch reefs in the Persian Gulf and on the Great Barrier Reef show that shoals are occurring around the platforms with lagoons forming inside. Carbonate sands occur mainly on the high area where wave and current actions are relatively strong, and lime mud is winnowed downwind toward the lagoonal areas. Reefs, if present, are best developed on the windward side of topographical highs. The shape of the platform is variable. Figure 3.6 is a cartoon showing depositional facies of the pure carbonate platforms of either the Cave Temple Member or the Doi Long Formation. Skeletal debris, resulting from resistance of skeletal grains to wind, wave and current actions, accumulates downwind and forms a tail morphology. The skeletal debris decreases in size downwind. Conversely, mud content increases toward the lagoon. Bioturbation is common in lagoons. Skeletal packstone (C5) and grainstone (C12) dominate in the shoal environment of deepening-upward succession of the drowned platform while peloidal algal packstone microfacies (C4) is predominant in the shoals of the shallowing platform. This difference may be due to age difference that provided

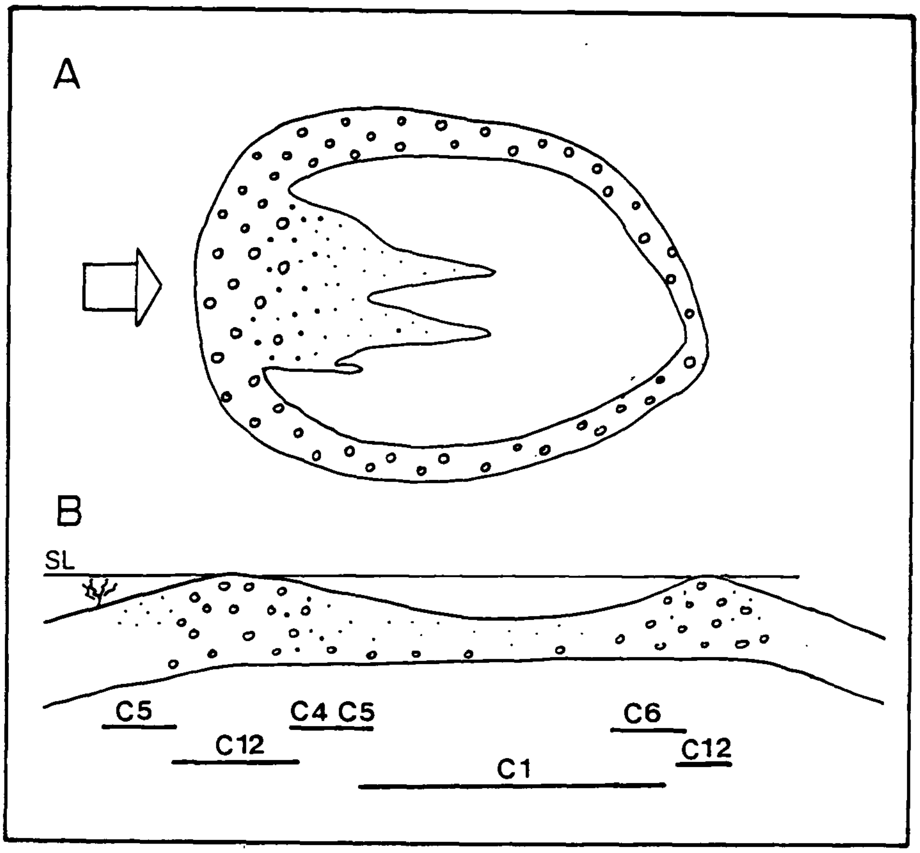


Fig. 3.6 Depositional facies of "pure" carbonate drowned ramp and regressive platforms surrounded by shallow marine environments; a) top view, b) cross section.

different living organisms. Skeletal packstone (C5) and grainstone (C12) are also deposited in channels. Like modern occurrence in the Persian Gulf, the lagoon may have been surrounded by tidal flats with stromatolites (C6). The scarcity of stromatolite in the Lampang Group may be explained by animal activity. Folk (1974) claimed grazing activities are the main factor reducing stromatolites while Pratt (1982) argue for the substrate occupation of the animals, based on evidence of many stromatolite occurrences that are associated with grazing animals.

Essentially the same depositional model may be applicable to both the Pha Kan and the Kang Pla Formations- that is, both probably represent a drowned ramp platform. Figure 3.7 shows the speculative development of a drowned ramp using as an example the Pha Kan Formation that can roughly be subdivided into two stages. It shows how a shallow, drowning ramp was formed. In stage 1, the Wiang Sawan and Chang Garb Members were formed in carbonate ramp and tidal environments, respectively. Sea level rose in stage 2. The carbonate platform tried to keep pace with the sea-level, resulting in shoreward migration of the platform (Muang Kham Member) which overlies the Wiang Sawan and Chang Garb Members. However, some offshore areas may have been able to keep pace with the sea-level rise and formed a shallow ramp (Cave Temple Member). The remaining platforms were drowned and buried beneath deeper marine clastics (Hong Hoi Formation). Evidence supporting this interpretation is provided by the succession of the Pha Kan Formation at Phra That Muang Kham temple (Fig. 2.4 A) which represents the right portion of Figure 3.7, whereas the left portion of the Figure 3.7 is represented by the succession at km 647.5 (Phra Thu Pha section, Fig. 2.4 G) on the Phaholyothin highway. The gradational contact passing upward from oncolites (Wiang Sawan Member) to pure carbonates (Cave Temple Member), at the km 647.5, suggests rapid sea-level rises.

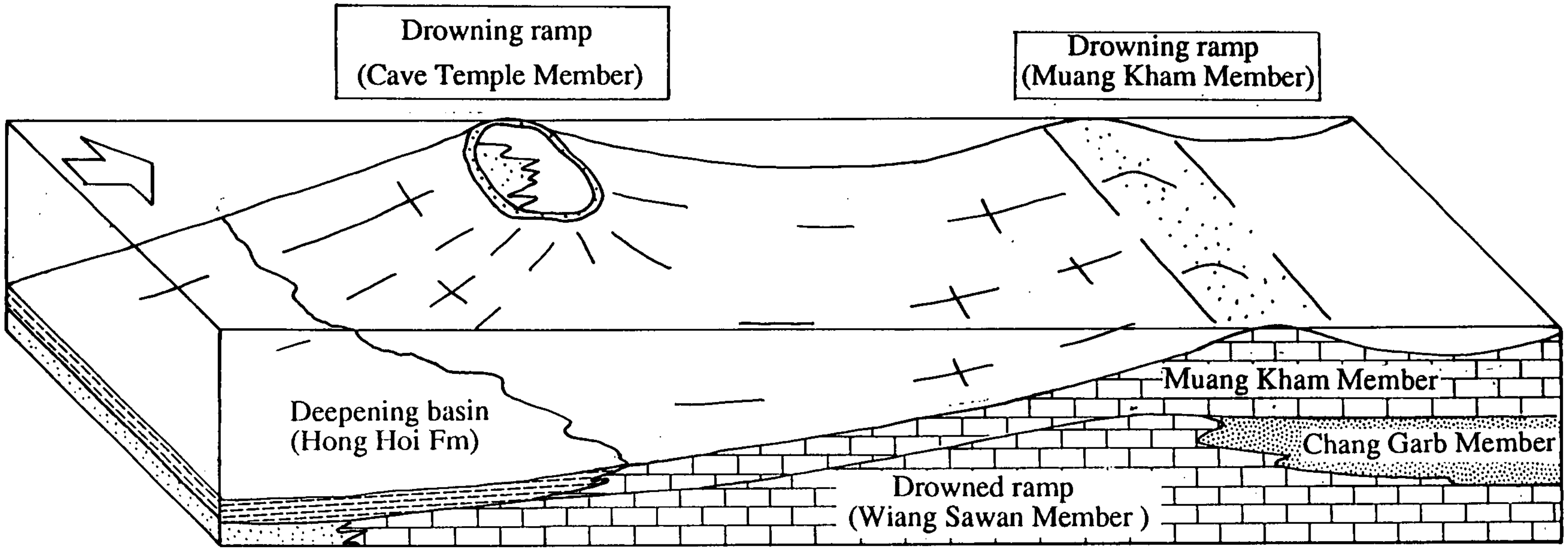


Fig. 3.7 Cartoon showing development of ramp platform to drowned ramp platform, as in the Pha Kan Formation. The Kang Pla Formation may have been formed in a similar fashion.

Chapter 4 : Clastic lithofacies and depositional environments of the Hong Hoi and Wang Chin Formations

4.1 Introduction

The Hong Hoi and Wang Chin Formations are mud-rich, gravity flow successions that form major parts of the Lampang Group, in the Lampang and Phrae sub-basins, respectively. They are significantly taken as key formations in discussion of the continent-continent collision between the Shan-Thai and Indochina terranes. Both formations are similar in lithology and sequences, and consist mainly of mudstones, subordinate unchannelized sandstones and minor conglomerates. As a result of this similarity, they have been previously grouped together under the name of Hong Hoi Formation (e.g., Piyasin, 1972; Bunopas, 1981; Chonglakmani, 1981; Helmcke, 1985; Chonglakmani and Helmcke, 1989). This problem, however, has been clearly unravelled in chapter 2. It is suggested that special attention should be paid to the use of the stratigraphic names from previous published papers.

Sediments of Hong Hoi and Wang Chin Formations have been interpreted in different ways: forearc sediments (Chonglakmani, 1972; Bunopas, 1981; Sengör, 1984), neritic sediments (Hahn and Siebenhuner, 1982), and post-collisional sediments in a rapidly subsiding shallow-intermontane basin (Helmcke and Lindenberg, 1983; Helmcke, 1985; Chonglakmani and Helmcke, 1989). Evidence for turbidite sedimentation is out of the question. Although turbidites can occur in either shallow or deep water environments, combination of the lack of cross stratification created by either tidal currents or storms, facies association and vertical sequence suggest submarine fans with detached sand bodies for most of the Hong Hoi and Wang Chin sediments. In some places, they also show a close association with shallow-water clastics.

Since there has been no facies study of these two formations, the purpose of this chapter is to describe their lithofacies, and then demonstrate their depositional environments and paleogeography.

4.2 Facies of the Hong Hoi and Wang Chin Formations

Sediments of the Hong Hoi and Wang Chin Formations can be subdivided into seven facies on the basis of lithology and sedimentary structures. Most outcrops have steeply dipping beds and poor lateral exposures which hamper lateral investigation. Despite these difficulties, the sections studied were taken from well-exposed outcrops along the Lampang-Denchai and Rong Kwang -Ngao highways which cut across the main structural trends in the southern and northern part of the study area, respectively, and from Huai Mae Dum through Huai Muang, the type section of the Hong Hoi Formation, in addition to several relevant locations. The important characteristics of each facies are summarized in Table 4.1.

4.2.1 Facies T1 : Structureless conglomerates

Facies T1 ranges in composition from clast- to matrix-supported conglomerates (Figs. 4.1 A, B). It has poor sorting and no internal orientation. Both planar and low-angle erosional basal beds are present, with the latter common in the matrix-supported conglomerates (Fig. 4.1 B). Clasts are round to subround, generally less than 30 cm in size (range up to a few meter thick) and consist mainly of volcanics and platform limestones. The facies ranges in thickness from a few centimeters to 10 m or more. Olistostromes are included in this facies. Facies T1 often grades upward to sandstones of Facies T3 and mudstones of Facies T6. Orientation of clasts may be present in the transitional zone.

Facies T1 represents about 5% of the Lampang sequences, exposed, for example, at km 650 on the Phaholyothin highway (at Chao Pho Phra Thu Pha sacred place), km 4 along the canal road to the Mae Chang Dam, Huai Chan and at Huai Muang.

Interpretation : The low diversity of clast lithologies, consisting mainly of volcanics and platform limestones, and the roundness of clasts imply short-distance transportation from sources and intensive rolling. Such a condition is similar to those of near-shore environments where currents are active and round the clasts. The combination of matrix-supported and structureless textures and the lack of characteristics of beach deposits, such as imbrication and cross stratification (in associated facies), suggests that these near-shore sediments were later remobilized

Table 4.1 Important characteristics of the Hong Hoi and Wang Chin submarine fans.

Facies	Grain size	Sorting	SS:MD ratio	SS/MD contact	SS bed thickness*	Bed form	Facies r/ship.	Approx. exposure %	Analogy	Sedimentary structures	Interpretation
T1 : Structureless conglomerates	boulder-sand	v. poor	>> 10:1	sharp with low angle erosion	≤ 10 m (cgl)	poor lat.-cont.	T3, T6	< 5	Facies A (Mutti & Ricci Lucchi, 1972); Class A (Pickering et al., 1989)	structureless, clast- to matrix- supported, planar-erosive basal beds	inner fan, proximal channel fill, rapid deposition, grain flow and debris flow
T2 : Massive bedded sandstone	c-m sand	poor	> 10:1	sharp planar	0.5 - 4 m	poor lat. cont.	T3,T4	< 5	Facies B (Mutti & Ricci Lucchi, 1972); Walker, 1984	structureless, amalgamated beds, planar basal bed, common wood fossils and ripped-up mud clasts	middle fan, channel fill, rapid deposition, grain flow
T3 : Turbidite sandstones	c-f sand	mod.	> 3:1	sharp planar	≤ 60 cm	non-parallel	T1,T2, T4	10	Facies C (Mutti & Ricci Lucchi, 1972)	Bouma Tab(cd), wood fossils, common ripped-up mud clasts, no flute structures	?middle fan, channel fill, low concentration turbidity current
T4 : Sandstone & mudstone with upward thinning cycles	c-f sand	mod.-good	2:1-1:1	sharp	5 - 30 cm	planar& wavy	T2, T3, T7	15	Facies E (Mutti & Ricci Lucchi, 1972); Mutti, 1977; Walker, 1985	Bouma seq., rare channel structures, common ripped-up mud clasts	middle fan, channel margin-levee, low concentration turbidity current
T5 : Thin parallel bedded sandstone and mudstone	m-f sand mud	good	≤ 1:1	unchannel ized	3 - 10 cm	planar parallel	T6	20	Facies D (Mutti & Ricci Lucchi, 1972); Walker, 1985	Bouma with base missing	outer fan, distal turbidites, low concentration turbidity current
T 6 : Mudstone associations	mud	good	<< 1:4	unchannel ized	< 3 cm	planar parallel	T1, T5, C13	40	Facies D (Mutti & Ricci Lucchi, 1972); Facies E (Piper, 1978); Walker, 1985	lamination, grading, trace fossils (*Chondrites*, *Planolites*)	basin plain, overbank, low concentration turbidity current
T 7 : Disturbed strata	sand, mud	poor	< 2:1	-	-	variable	T1, T4, C13	< 5	Facies F (Mutti & Ricci Lucchi, 1972)	slump	failure strata, channel levee

*Thickness of sandstone beds except where specified.

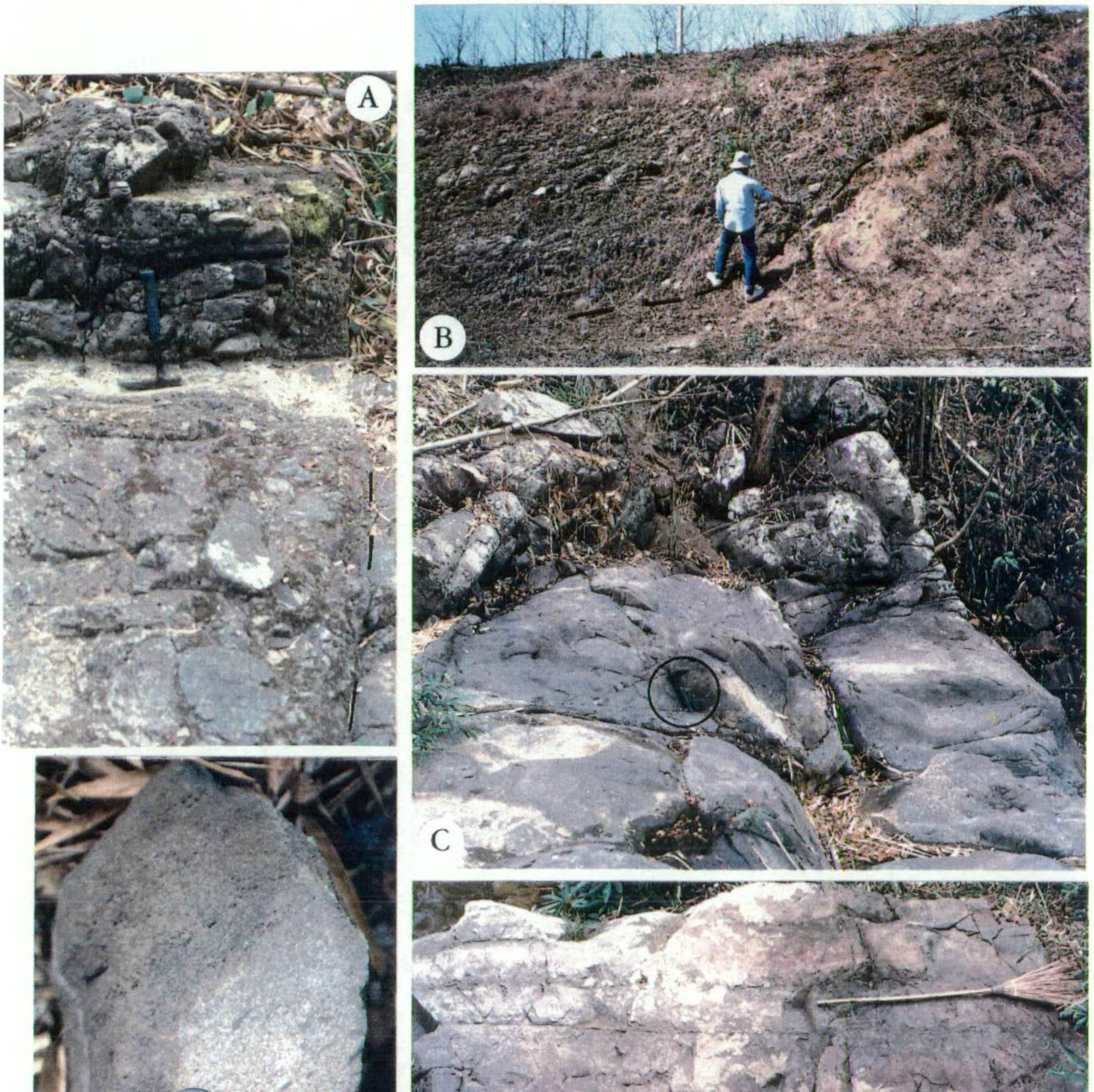
Figure 4.1 Photographs of Facies T1, T2 and T3.

A) Clast-supported and massive conglomerate of Facies T1 showing low-angle erosional basal contact (dashed line) with sandstone; clasts consist mainly of volcanic rocks, Mae Dum Sandstone Member of Hong Hoi Formation at Huai Muang, Ban Tha Si (top to the left).

B) Matrix-supported conglomerate of Facies T1 with erosional basal bed, incised into mudstones; Hong Hoi Formation at km 4+ 220 m on the Mae Chang canal road.

C) Massive bedded sandstone of Facies T2, Mae Dum Sandstone Member of Hong Hoi Formation at Huai Mae Dum, hammer for scale (in the circle).

D, E & F) graded sandstones of Facies T3 of Mae Dum Sandstone Member at Huai Mae Dum, **D)** showing nonparallel beds and lag deposits (immediately below the hammer) suggestive of channel deposits, **E)** lamination (Tb) and ripple stratification (Tc), and **F)** coarse-grained sandstones with ripped-up mud clasts (black fragments). Camera cap is 5 cm in diameter.


A
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Tc
Tb

downslope, possibly due to slope failure caused by earthquakes. Lack of deep erosional structures and the rare occurrence of the facies suggest that Facies T1 is unlikely to represent a canyon deposit, although the channel structures of slope facies of mud-dominated fans are less pronounced (Pickering et al., 1989). Facies T1 is interpreted as channel deposits in inner submarine fan environments. The clast-supported conglomerates may have been formed by grain-flow processes where sediments are carried by the result of grain-to-grain collision, whereas the matrix-supported conglomerates were deposited by debris flow processes where the sediments are carried by cohesive strength in a mixture. Postma (1986) stated that the presence of clay as low as 5% in the mixture of clay and solids gives the mixture cohesive strength and makes it able to sustain larger clasts. To generate grain flow requires a slope of 18° to 37° (Middleton and Hampton, 1973) while debris flow can move on slopes as low as 0.5° (Stow, 1986). By analogy, Facies T1 is similar to Facies A of Mutti and Ricci Lucchi (1972) and Facies Class A of Pickering et al. (1989).

4.2.2 Facies T2 : Massive bedded sandstone

Facies T2 is poorly sorted, matrix- to grain-supported, medium to coarse grained gray sandstone. It occurs in packets 50 cm to 4 m thick which feature nonparallel bedding, poor lateral continuity, sharp and planar basal surfaces, and no internal fabric organization and dish structures (Figs. 2.13 G, 4.1 C, 4.2). The upper part of beds may show grading. Other common characteristics are amalgamated beds, ripped-up mud clasts and coalitized wood fragments; the amalgamated beds can be distinguished by layers of these two clasts. The sandstone to mudstone ratio is greater than 10:1; and interbedded mudstone is rare. Facies T2 is often overlain by the coarse-grained sandstone of Facies T3 and the thin bedded sandstone of Facies T4.

Facies T2 has the distinctive feature of massive beds and is therefore easy to recognize. It represents less than 5 % of the Hong Hoi (Fig. 2.6A) and the Wang Chin Formations (Fig 2.12).

Interpretation : Facies T2 is interpreted as being rapidly deposited as channel fill in middle fan areas by grain flow processes. The occurrence of amalgamated beds, ripped-up mud clasts and coalitized wood fragments indicate channel sedimentation. Lack of internal structure suggests rapid deposition from deceleration of a highly concentrated flow (Postma, 1986). Occurrence of grading in the upper part of some beds suggests that the flows became a turbidity current of high concentration. The absence of dish structures, which commonly occur in massive sandstones elsewhere, may be due to an inadequate amount of clay in the sediments (Collison and

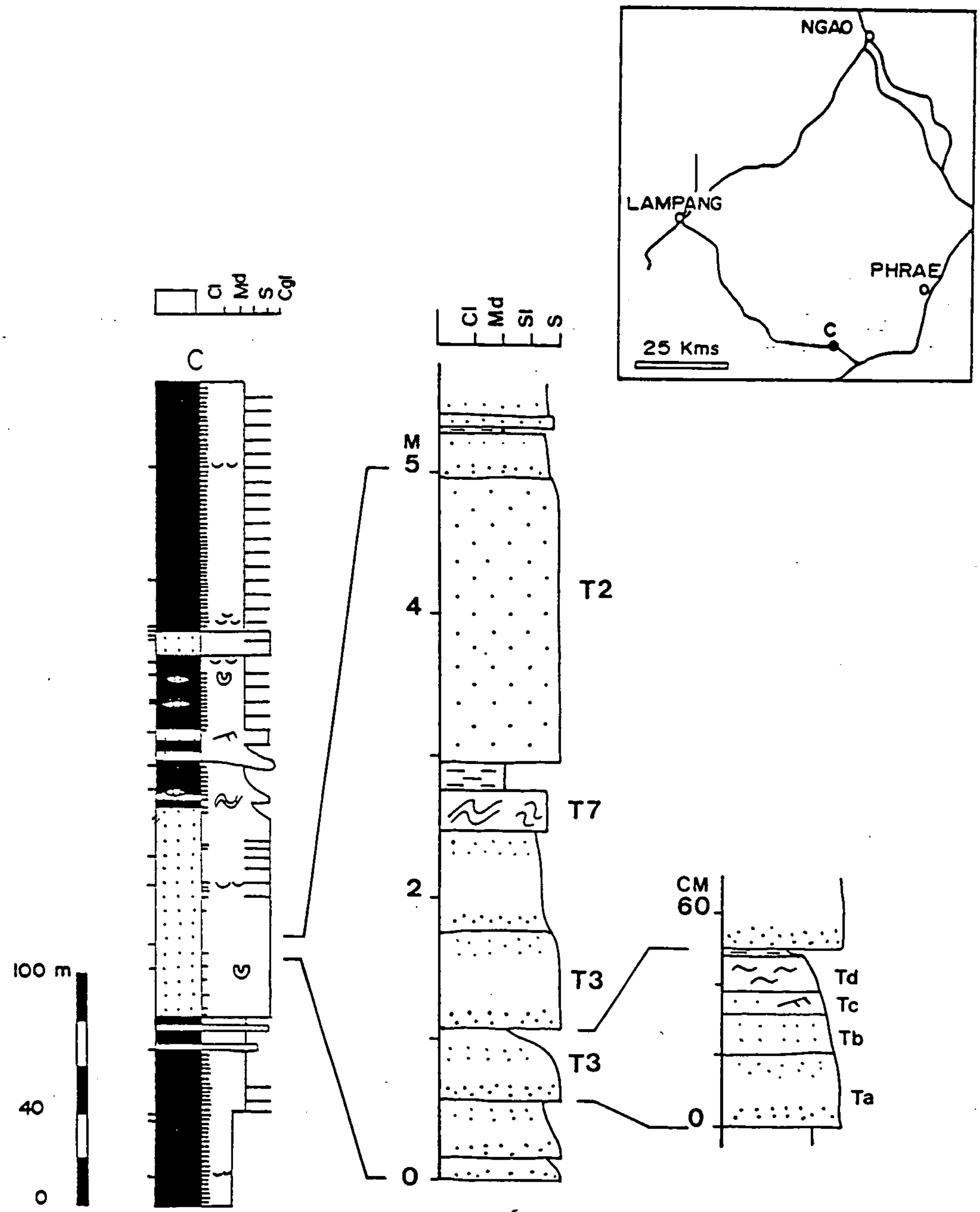


Fig. 4.2 Detailed facies association of marine turbidites including massive sandstone (T2), turbidite sandstone (T3) and slump strata (T7); Mae Lu Sandstone Member of Wang Chin Formation at km 66 + 490 m on the Lampang-Denchai highway.

Thompson, 1982). Facies T2 is analogous to Facies B of Mutti and Ricci Lucchi (1972), and the massive sandstone of Walker (1978, 1984), interpreted as channel deposits in a submarine fan.

4.2.3 Facies T3 : Turbidite sandstones

Facies T3 consists of coarse-to fine-grained, thick-to thin-bedded sandstones and mudstones that display Bouma sequence (Figs. 2.9 B, 4.1 D, E, F). Sandstones have nonparallel beds, planar basal contacts, no flute structure, often show massive texture and grading of Bouma Ta, lamination (Tb), and rare cross stratification (Tc). Ripped-up mud clasts and coalitized wood fragments are common in the basal beds. Lag deposits may be present (Fig. 4.1 D). Burrows may occur in mudstones. The sandstone to mudstone ratio is greater than 3:1. Facies T3 is closely associated with massive sandstone of Facies T2, the conglomerates of Facies T1 and sandstone and mudstone of Facies T4.

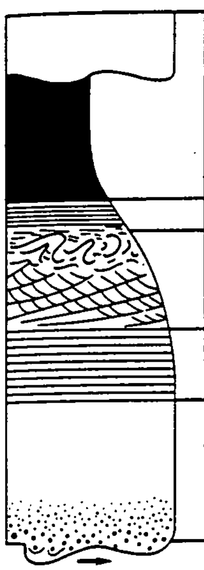
Facies T3 crops out in Huai Mae Dum and km 66.5 on the Lampang-Denchai highway.

Interpretation : Facies T3 is interpreted as middle fan channel sediments. Bouma sequence is believed to have been formed by turbidity currents in which Bouma Tb-e were deposited by low concentration flows while the structureless and graded texture in Ta are more akin to deposits of high concentration flow (Pickering et al., 1989, p 20). The ideal Bouma sequence with interpretation, from Pickering et al. (1989), is given in Figure 4.3. The mud clasts are possibly related to erosional surfaces created by turbidity currents during transportation. Lack of flute structures suggest the currents were of low velocity. Facies T3 differs from the proximal turbidites of Walker (1978) in lacking of the prominent sole marks, and is similar to Facies C of Mutti and Ricci Lucchi (1972) which are interpreted as channel fill sediments.

4.2.4 Facies T4 : Sandstone and mudstone with upward thinning cycles

Facies T4 is a sequence of turbidite sandstone and interbedded mudstones in which the thickness of sandstone beds decreases up the sequence (Figs. 2.13 B, D, 4.4 A, 4.5). Sandstone beds are planar, wavy and in a few places lenticular, and generally range in thickness from 10-30 cm (with a maximum of 80 cm) in the lower part to 5-10 cm in the upper part of the sequence, within a sequence of 20-400 cm thick. Sandstone is gray, coarse to fine grained, commonly displaying normal grading, lamination and rare cross-stratification. Coalitized wood fragments and ripped-up mud clasts are common in the thick basal beds. Mudstones are gray and thinner; the sandstone to mudstone ratio is 2:1 to 1:1. The thinner beds tend to have the lower ratio. Burrows are common in the mudstones. They are unnamed and of a peculiar form consisting of vertical to inclined pairs of parallel burrows filled by sandstone. They are about 0.5-1 cm in diameter and up to 5 cm long (Fig. 2.13 C). No U-shape has been observed, although some show curved-end (Fig. 4.4 B). Bivalves are locally abundant in mudstone where the sandstone to mudstone ratio is low, and most shells lie convex side-up. Facies T4 is often associated with massive bedded sandstone of Facies T2 and slump strata of Facies T7. Facies T3 is similar to part of Facies T4 and differs from Facies T4 in the lack of vertical asymmetric cycles and having poorer lateral continuity of beds.

Facies T4 crops out along Huai Mae Dum- Huai Muang (Fig. 2.6) and at km 55 + 240 m and 55 + 800 m on the Lampang-Denchai highway (Fig. 2.12 B).



GRAIN SIZE	BOUMA (1962) DIVISIONS	INTERPRETATION
Mud	E Laminated to homogeneous mud	Deposition from low-density tail of turbidity current ± settling of pelagic or hemipelagic particles
Silt	D Upper mud/silt laminae	Shear sorting of grains & flocs
Sand	C Ripples, climbing ripples, wavy or convolute laminae	Lower part of lower flow regime of Simons *et al* (1965)
	B Plane laminae	Upper flow regime plane bed
Coarse Sand	A Structureless or graded sand to granule	Rapid deposition with no traction transport, possible quick (liquefied) bed

Fig. 4.3 Graphic of Bouma sequence showing sedimentary structures and interpretation (from Pickering et al., 1989).

Figure 4.4 Photographs of Facies T4, T5 and T6.

A) Sandstones and interbedded mudstones of Facies T4 showing typical laterally thinning beds (arrow). Note variation in bed thickness; beds thin toward channel margin; Mae Lu Sandstone of Wang Chin Formation at km 55 + 242 m on the Lampang-Denchai highway. Hammer for scale.

B) Burrows in mudstones, terminated by the overlying sandstone bed; same location as Fig. 4.4 A. Camera cap is 5 cm in diameter.

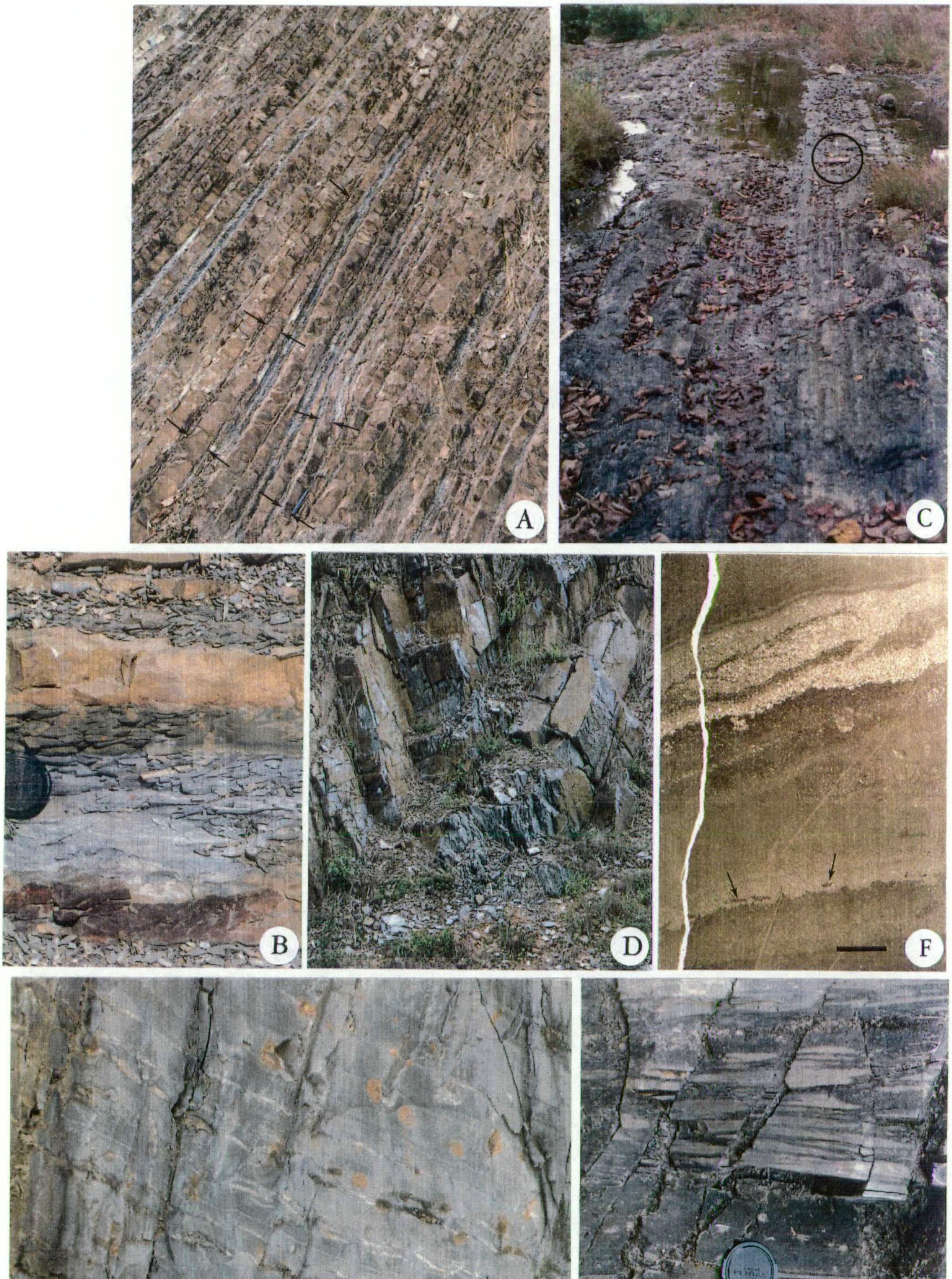
C) Typical characteristics of Facies T5 displaying parallel beds of sandstones (thicker beds) and interbedded mudstones (thinner beds), Hong Hoi Formation at Huai Mae Dum; field book (12 by 18.5 cm) in the circle for scale.

D) Mudstones and thin (< 3 cm) interbedded sandstones of Facies T6 interpreted as basin plain deposits; Phu Tap Member of Wang Chin Formation at km 64.8 on the Lampang-Denchai highway.

E) Mudstone and thinly (about 1 cm) interbedded sandstone and siltstone of Facies T6. The sandstone beds were originally continuous; Phu Tap Member at km 54.8 on the Lampang-Denchai highway.

F) Photomicrograph of Facies T6 showing microerosional basal sandstone beds, with ripped-up mud clasts (arrow) and both gradational and abrupt upper contacts; crossed polar; same location as Fig. 4.4 E; bar scale is 1 cm.

G) Facies T6 showing discontinuous thin beds of sandstones, interpreted as overbank deposits; Phu Tap Member at km 66 + 557 on the Lampang-Denchai highway; camera cap is 5 cm in diameter.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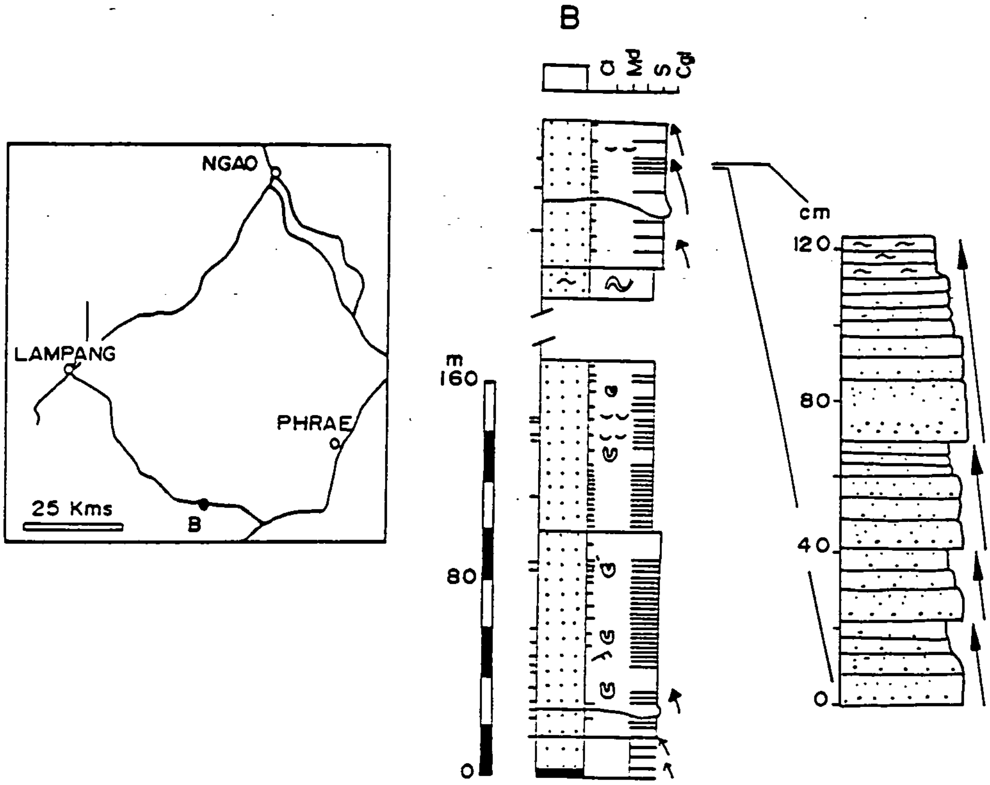


Fig. 4.5 Detailed thinning and fining upward cycles of Facies T4, Mae Lu Sandstone Member of Wang Chin Formation at km 55 + 200 m on the Lampang- Denchai highway.

Interpretation : Interbedded sandstone and mudstone with ~~a~~ an upward thinning sequence is well documented from channel and levee to interchannel deposits of the middle submarine fan (Mutti and Ricci Lucchi, 1972; Hiscott, 1981; Walker, 1978, 1985), and in the channelized middle part of the alluvial fan (Heward, 1978; Nilsen, 1982). The associated marine fossils, *Halobia*, suggest a marine environment and, thus favors the former case. The occurrence of sandstones with good lateral continuity of beds, high sandstone to mudstone ratio, ripped-up mud clasts and uncommon channel structures suggest channel margin to levee environments for Facies T4. Mutti (1977) noted that thin-bedded sandstone and mudstone of interchannel deposits has low sandstone to mudstone ratio (0.4-0.5) and sandstone beds 1.5-4.0 cm thick; and these values are lower than those of Facies T4. A laterally thinning bed that its thicker part containing coarser graines and showing upward grading implies channel margin facies in which the bed thins towards the margin (Fig. 4.4 A).

Thinning-upward sequences can be created by 1) progressive migration of an active channel away from the depositional site (Ricci Lucchi, 1975; Walker, 1985), 2) channel abandonment (Hiscott, 1981), 3) bypassing of currents over or around topographically high sand deposits (Ricci Lucchi and Valmori, 1980), and 4) lateral lobe switching from lobe center to lobe fringe (Walker, 1984). Burrows were possibly formed during sluggish currents where mudstones were deposited. Lack of burrows in the overlying sandstones suggests that incoming turbidity currents for sandstone deposition were too strong, disfavoring burrowing activities. The general convex side-up orientation of bivalves is indicative of current deposition. Facies T4 is similar to Facies E of Mutti and Ricci Lucchi (1972) and thinning and fining upward turbidites of Walker (1985), interpreted as channel margin to interchannel sedimentation in a submarine fan.

4.2.5 Facies T5 : Thin parallel bedded sandstone and mudstone

Facies T5 is characteristically unchannelized, parallel thin-bedded (3-10 cm) sandstones and interbedded mudstones in which the sandstone to mudstone ratio is about 1:1 or less (Figs. 2.9 A, 4.4 C). Beds have a very good lateral continuity. Sandstone is gray and fine- to medium-grained, displaying Bouma sequences with base missing. Contact of sandstone with the underlying mudstone is always sharp but with the overlying mudstone is either gradational (common) or sharp. There may be rare tiny bivalves, 2-5 mm in size, and bioturbation in the mudstone.

Interpretation : Facies T5 is interpreted as outer fan deposits where sedimentation is unconfined. This interpretation is supported by good lateral continuity of beds, texture of Bouma sequence with base missing and lack of coarse-grained, medium- to thick bedded sandstones and channel structures. Unchannelized sequences are characteristic of the outer fan while channelized sequences represent the inner and middle fans of submarine fan environments (Shanmugam and Moiola, 1988). Facies T5 is analogous to distal turbidite of Walker (1978) and Facies D of Mutti and Ricci Lucchi (1972), interpreted as outer fan and basin plain of submarine fan.

4.2.6 Facies T6 : Mudstone associations

Facies T6 is characterized by mainly mudstones and subordinate thinly interbedded siltstones and fine-grained sandstones (Figs. 2.13 E, F, 4.4 D, E). Sandstones commonly show micro-erosional basal beds and either gradational or sharp upper contacts (Figs. 2.13 F, 4.4 F). The sandstone to mudstone ratio is less than 1:4; sandstone and siltstone beds are lighter in color and, generally, less than 3

Figure 4.6 Photographs of Facies T6 and T7.

A) Abandoned channel sandstones with sharp upper contact,in mudstones of Facies T6; Phu Tap Member of Wang Chin Formation at km 66 + 575 on the Lampang-Denchai highway.

B) Trace fossils, possibly *Chondrites,* of Facies T6; Phu Tap Member at km 34 + 325 on the Rong Kwang-Ngao highway.

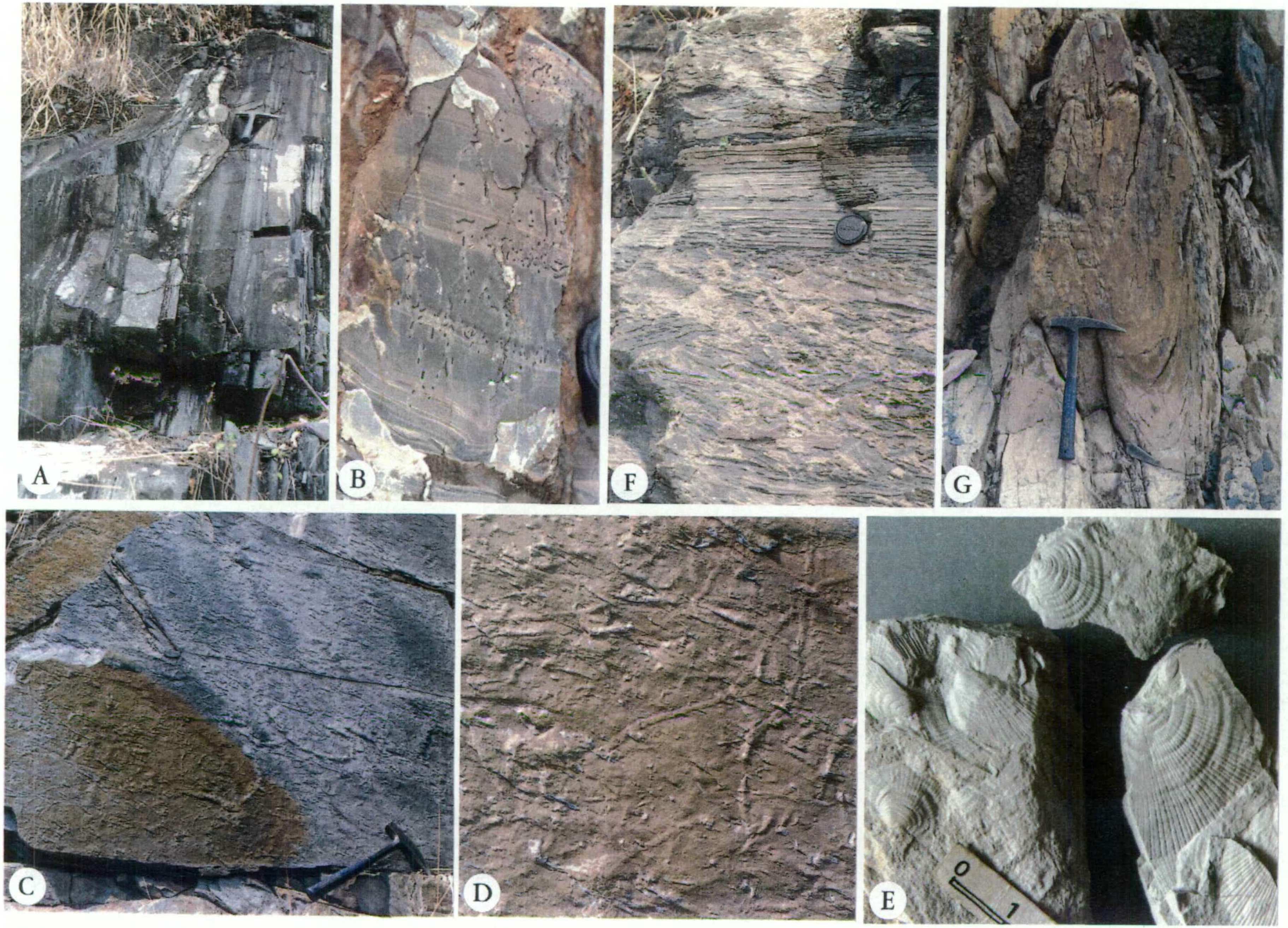
C) Trace fossils, *Planolites* (small tabular) and unknown ichnospecies; Phu Tap Member of Wang Chin Formation at km 64 + 850 on the Lampang-Denchai highway.

D) Enlargement of the lower left corner of Fig. 4.6C.

E) *Halobia* sp. from km 55 +525 on the Lampang - Denchai highway; Mae Lu Sandstone Member; bar scale in centimeter.

F) Slump strata of Facies T7; Phu Tap Member of Wang Chin Formation at km 66 + 555 on the Lampang-Denchai highway.

G) Slump strata of Facies T7; Huai Chan Member at Huai Chan.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Interpretation : In submarine fans, slumps commonly occur along slope and channel-levee environments, where the gradient is generally steep. Facies T7 is incompatible with slope environments because it is small in scale and has no large erosional channel cutting in to mudstones indicative of slope deposits. Its occurrence, commonly associated with sediments of channel and levee environments (Facies T2, T3 and T4), suggests such an environment for Facies T7. By analogy, it is similar to Facies F of Mutti and Ricci Lucchi (1972), interpreted as failure strata.

4.3 Hong Hoi and Wang Chin turbidites: an interpretation of submarine fan environments

Prior to discussion of the Hong Hoi and Wang Chin turbidite systems, a general background to deep-sea turbidite depositional systems is provided.

Depositional systems of deep-sea sediments have been classified in different ways. Mutti and Ricci Lucchi (1972) proposed the seven classical facies models, A through G, to recognize submarine fans, and the general concept of these have now become widely accepted (Table 4.2). Pickering et al. (1986, 1989) took an entirely descriptive approach to modify the facies of Mutti and Ricci Lucchi (1972) and Walker and Mutti (1973). Their deep-sea sediments consist of 41 facies. Shanmugam and Moiola (1988) classified submarine fans, based on tectonic settings, into four types: immature passive-margin, mature passive-margin, active-margin and mixed setting. Their immature passive-margin and active-margin fans are similar in characteristics: that is, they are usually small, sand-rich and possess well developed lobes, whereas their mature passive-margin fans are large and mud-rich, having no typical lobes and also having sheet sands in the lower-fan regions. However, many known active-margin submarine fans are mud-rich, such as the Delgata, Magdalena, Crati, and Frigg Field (Bouma et al., 1985). Recently, Reading (1991) showed that deep-sea depositional systems should be better classified by sediment caliber and feeder systems, either mud- or sand-dominated systems in the former, and single or multiple sources in the latter. In spite of these differences, there is a general agreement that deep-sea sediments consist of two major types: mud dominated and sand dominated.

Modern and ancient deep-sea sediments can be subdivided into three major environments: slope-aprons, submarine fans and basin plains (Mutti and Ricci Lucchi, 1972; Walker, 1978; Bouma et al., 1985; Stow, 1986; Shanmugam and Moiola, 1988; Pickering et al., 1989; Reading, 1991). Slope-aprons are located between the shelf and the basin floor, a site for erosion and the initiation of resedimentation processes, and have multiple point sources parallel to the margin. The basin plain is the deepest

Table 4.2 Summary of principal characteristics of turbidite facies, according to Mutti and Ricci Lucchi, 1972 (from Shanmugam and Moiola, 1988,1991)

Facies	Lithology	Bedding	Features	Depositional processes
A	Conglomerate, coarse sandstone	Thick, irregular, amalgamated	Channel fill, shale clasts, poor sorting	Debris flows, liquified flows
B	Coarse to medium sandstone	Thick, lenticular	Channel fill, shale clasts, dish structures	debris flows, liquified flows, turbidity currents (high energy)
C	coarse to fine sandstone, minor shale	Medium, continuous	Complete Bouma sequence	Turbidity currents
D	Fine to very fine sandstone, siltstone, shale	Thin, remarkably continuous, parallel	Bouma sequence with base missing	Turbidity currents (low energy)
E	Sandstone, siltstone	Thin to medium, irregular, discontinuous	Beds with sharp upper contacts	Liquified flows, turbidity currents, traction currents (?)
F	Complex	Chaotic	Slumps	Slumps, debris flows
G	Shale, marl	Laminated, remarkably continuous, parallel	Homogeneous texture	Pelagic & hemipelagic sedimentation

part of the basin and has a broad area. The submarine fans have a point source and are usually deposited beyond the continental shelf break at the foot of the slope between the slope-apron and the basin plain. They are classified on the basis of sediment caliber into two types: mud-dominated and sand-dominated fans. The former are characteristically elongated, large open basins, highly efficient (that is able to carry sands for a long distance) and often showing detached fan lobes. They are normally fed by a major delta and are similar to a fan in channel-levee complexes. The latter are characterized by radial morphology, relatively small restricted basins, low-efficiency (i.e. sands deposited next to the channel mouth), and are similar to attached fan lobes. They have a canyon feeder system and correspond to a fan in channel-lobe complexes. Stow (1986) also considered a fan delta as a third type of submarine fan; however this is denied by Shanmugam and Moiola (1988) on the basis that fan deltas are of shallow-water origin.

Conventionally, submarine fan components for modern settings are described as upper, middle and lower divisions while for the ancient settings inner, middle and outer divisions are preferred (Shanmugam and Moiola, 1988). In general, the inner fan is recognized by the presence of a major feeder channel (mud-dominated fans are often represented by slump scars and broad erosional surfaces that grade imperceptibly into the continental slope), the middle fan by a network of distributary channel and associated overbank deposits, and the outer fan by unchannelized sands or sheet sands.

Paleogeography can be reconstructed by correlating lateral facies variation between proximal and distal turbidites. Criteria to distinguish these sediments is provided by Stow (1986, and Table 4.3). In general, from proximal to distal the values of sandstone to mudstone, sandstone thickness, grain size and erosive features (amalgamated beds, channels) all decrease; scour marks (e.g., flutes) become fewer and tool marks (e.g., grooves) become more in number; beds become more regular, parallel sided and better-graded.

4.3.1 Hong Hoi and Wang Chin submarine fans

The Hong Hoi and Wang Chin sediments are interpreted, based on facies associations and vertical facies sequences, as mud-dominated submarine fan deposits with detached sand bodies. They consist mainly of overbank and channel-levee deposits (Table 4.1). Most sandstones display flat bases and no lobes. They are similar to submarine fans of channel-levee complex systems in that most coarse-grained sediments are confined within channel areas, and to submarine ramp model (Heller and Dickinson, 1985; Chan and Dott, 1983) in their feeder system of multiple-point sources; the latter is predominantly sands. They differ from fans of channel-lobe complexes (Shanmugam and Moiola, 1988) in having no lobes. Definition and types of submarine fan lobes are discussed at length by Shanmugam and Moiola (1991). The submarine ramp model differs from other submarine fan models (Mutti and Ricci Lucchi, 1972; Walker, 1978; Bouma et al., 1985a) in the absence of channelized inner fan and middle fan environments, and in the rarity to absence of symmetric packets or cycles (i.e. upward-thinning or-thickening cycles) (Heller and Dickinson, 1985).

During the Triassic Period, the sea-level curve was generally low (Fig. 4.6) that suits for sedimentation of deep-sea terrigenous sediments because the sediments can be directly carried through broad platform areas to continental shelf break and because instability and slumping of sediment piles accumulated in shelf and coastline areas during high sea-level stand (Stow et al., 1984). The lack of a large channel cutting into mudstones of slope facies that could have served as a single feeder point source and the rare occurrence of conglomerate facies suggest that the feeder system was possibly a multiple-point rather than single-point source. As a result of no a major channel, there is also no distinction between channel and overbank or interchannel deposits, and thus no lobes (Heller and Dickinson, 1985; Reading, 1991). These multiple-point sources may have initially been slumps and slides of shelf sediment piles, triggered by slope failure. Evidence supporting shelf-originated sediments includes: **1**) similarity in lithology between submarine sandstones of Hong Hoi and Wang Chin Formations and shelf sandstones of Chang Garb Member and Pha Daeng Formation, **2**) reworked sediments as suggested by interbeds of limestone conglomerate with shallow-marine limestone-clasts, and by their turbidite texture, and **3**) proximal sedimentation as indicated by sandstone composition of active volcanic sources that favors shelf rather than long transported, river-fed environments. Slope instability may be due to both tectonics and changes in sea-level. A drawdown in sea-level would tend to induce slope instability. Sedimentation rate was possibly high and rapid as suggested by rare occurrence of bioturbation in mudstones and by feldspar-rich sandstones. Evidence from the proximal origin of sandstones, the absence of canyon deposits and rare occurrence of conglomerates imply that the depositional basins had neither a steep gradient nor a high relief, and that the basins were unlikely to have been controlled solely by tectonics. Thus, the slump or slide scars were possibly shallow. Similar processes are reported from the Eocene forearc basin in western Oregon (Chan and Dott, 1983; Heller and Dickinson, 1985). Lack of obviously discernible channel structures may be due to the limited size of outcrop conditions. Most exposures along either the highways or creeks have a lateral length less than 50 m. The examples of modern Rhone and Eocene Hecho submarine fans have channel widths of 1-10 km and 0.1 km, and channel depths of 150-400 m and 10 m, respectively (Shanmugam and Moiola, 1988).

Table 4.3 Characteristics of proximal, medial and distal turbidites (after Stow, 1986)

	Proximal (coarse-grained)	Medial (medium-grained)	Distal (fine-grained)
Bed thickness	Thick	Medium and thin	Thin beds and laminae
Bed shape	Irregular; lensing, channels and washouts common	Parallel-sided; regularly bedded	Parallel sided beds and laminae, also discontinuous laminae
Sand/ Mud ratio	SS/MD high, amalgamation of sandstones, thin mudstone partings and layers	SS/ MD medium, rare amalgamation, well-developed mudstone layers	SS/ MD low, mudstone dominant
Grading	Beds often ungraded or poorly graded, some negative grading	Grading commonly well-developed	Grading often subtle and on very small scale
Facies models	Bouma T_{ae} sequences and Lowe sequences common	Classical Bouma sequences common (T_{abcde}, T_{bcde}, etc)	Stow/ Piper sequences common, Bouma $T_{(c)de}$ and T_e divisions only
Stratification	Large-scale parallel and cross-stratification common	Lamination, ripples and convolute lamination common	Interlaminated siltstone and mudstone common, micro-cross lamination etc.
Top and bottom structures	Base sharp, commonly scoured; top often sharp	Base sharp, minor scours; top usually graded	Base sharp, more rarely gradational, micro-scours; top sharp or gradational
Bioturbation	Mostly absent	Can be well-developed in mudstone layers	Can be well-developed; micro-bioturbation also common
Deformation structures	Slump and dewatering structures common	Minor slump and dewatering structures	Siltstone loading and balling in mudstone layers can occur
Grain size	Gravel and coarse-sand size dominant	Medium-fine sand size and interbedded mud-grade	Very fine sand and silt-size with mud-grade dominant
Sorting	Often poor	Moderate	Moderate to well-sorted
Composition	Immature and mixed components	Moderate maturity, compositional grading common	Mature, compositionally well-sorted
Associated facies	Slump and debrites	Fine-grained turbidites, some hemipelagites	Medium-grained turbidites, contourites, hemipelagites and pelagites

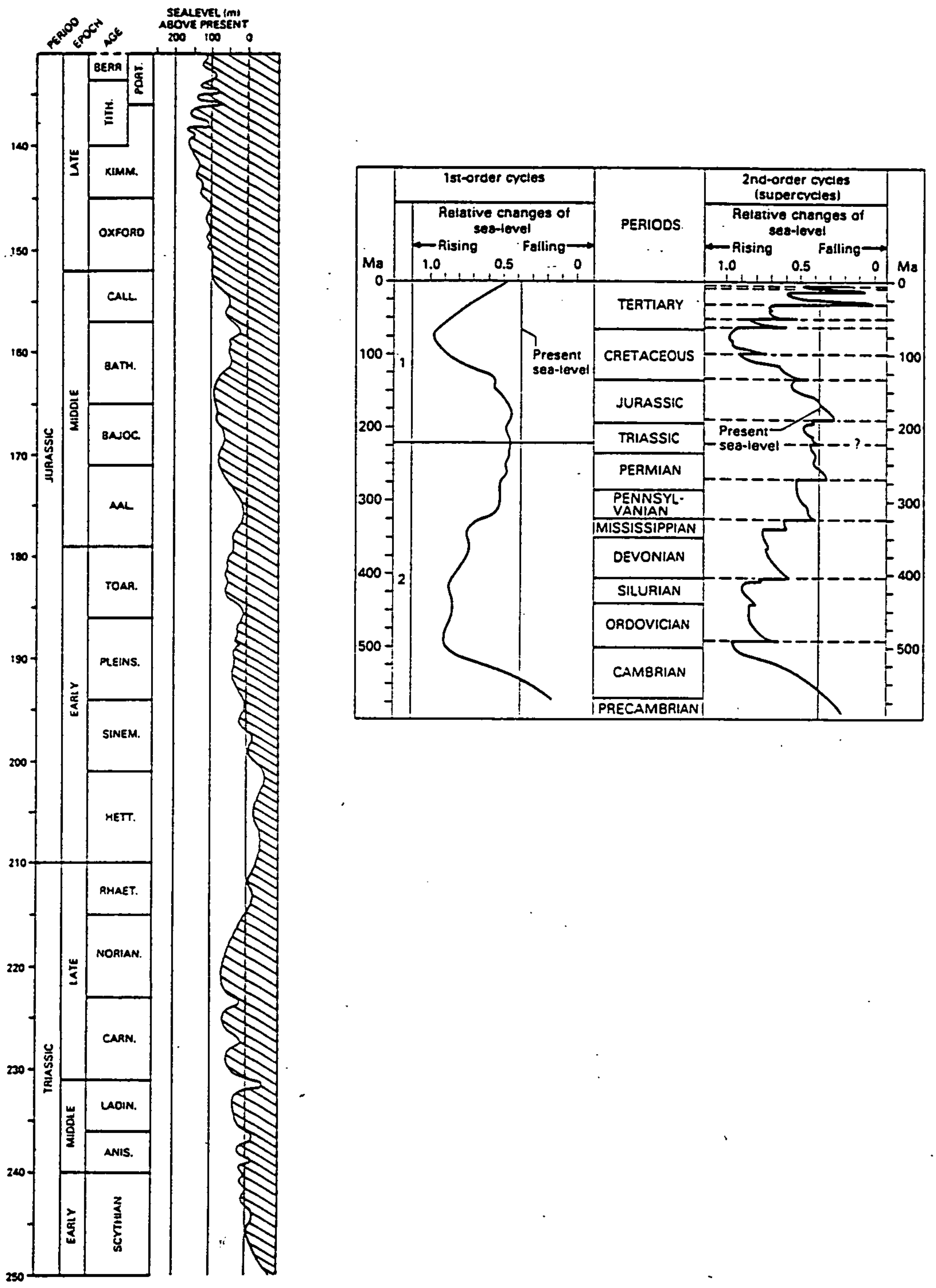


Fig. 4.7 Global cycles of relative change of sea-level during Phanerozoic Eon (right) showing first-order cycles (200-300 Ma) and second-order (10-80 Ma)(From Vail et al., 1977 in Reading, 1986), and in more detail for the Triassic and Jurassic Periods (left) showing third-order cycles (1-10 Ma) (from Haq et al., 1987 in Pickering et al., 1989).

Occurrence of predominant fine- grained terrigenous turbidites in the Lampang Group may be partly caused by climate and source rocks, since the group was deposited in a tropical climate (Bunopas, 1981) and consists mainly of volcanic fragments. Such conditions encourage chemical alteration and, thus, the final product could be mainly fine grains. Other factors that influence sediment caliber include the topography and tectonic activity in the source area, distance between source and depositional sites, and modes of transport (Stow et al., 1985).

Pelagic sediments are characterized by a considerable amount of biogenic materials (e.g., radiolaria and forams), slow sedimentation rate in the abyssal areas, deposition from suspension and vertical aggradation and absence of any substantial bottom current or turbidity current activity (Stow and Piper, 1984). Such sediments are rare in the Hong Hoi and Wang Chin Formations. They instead consist mainly of turbidite sediments. The majority of sediments in abyssal areas are noted as turbidites rather than pelagic or hemipelagic sediments (Jenkyns, 1986). Although there is no evidence to indicate how deep the sediments were deposited, the lack of pelagic radiolarian chert and the occurrence of limestone lenses in mudstones of Facies T6 suggest that the depth was above calcite compensation depth (CCD = about 4 km for low latitude, Tucker and Wright, 1990), and the lack of storm evidence suggests sedimentation took place below the storm wave base. Triassic radiolarian chert, however, has been reported from Mae Sariang Basin to the west (Fontaine and Suteetorn, 1986) and Nan Suture to the east (Hada, 1990).

Chonglakmani (1981) reported widespread distribution of deep marine sediments and fossils (mainly *Daonella*, *Posidonia* and ammonoids) during late Ladinian to early Carnian in the Lampang sub-basin, and local distribution (mainly *Halobia* and *Posidonia*) during middle Carnian to early Norian in Phrae sub-basin. Bivalves *Daonella*, *Posidonia* and *Halobia*, however, can occur both in shallow and deep marine environments, depending on their fauna assemblages; an assemblage without benthic fauna and brachiopods is likely to belong to deep marine environments (Chonglakmani, 1981). He, however, also regarded the deep marine bivalves as pelagic fauna.

4.3.2 Detached sand bodies

Sandstones of the Hong Hoi and Wang Chin Formations are mainly of middle fan channel-levee environments (Table 4.1). According to vertical sequences, the sandstones form stacks and are bounded by mudstones (Figs. 2.6, 2.10, 2.12). The lower contacts of the stacked sandstones commonly show signs of sudden occurrence with no obvious channel structures, while the upper contacts show gradation (i.e. decreases upward in proportion of sandstone to mudstone). Rare slump and inner-fan strata and a lack of slope sediments indicate that the stacked sandstones were headless or detached sand bodies. The origin of detached sand bodies may be due to: 1) sediment bypassing (Mutti and Ricci Lucchi, 1975), 2) morphological control such as sudden downward increase in slope (Shanmugam and Moiola, 1988), and 3) lithological control of low sand to mud ratio or mud-rich sediments (Bouma and Coleman, 1985, p 251).

4.4 Facies relationships and depositional environments of Hong Hoi Formation

The Hong Hoi Formation in the study area consists mainly of overbank and basinal mudstone facies (Facies T6) and subordinate channel and levee sandstone facies (T2-T5), and on the basis of current exposures was deposited in a narrow and long basin, in the present NE/SW, and parallel to the "Nan Suture".

Facies interpretation of the Hong Hoi fans here follows the measured sections at the type section and at Mae Chang canal road (Fig. 2.6). The Tha Si Member at the latter place consists of inner-fan deposits represented by shallow channel conglomerates (Facies T1) cutting into the mudstones of Facies T6 (Fig. 4.1 B). There is also an abandoned channel recognized by a coarse-sandstone channel that was suddenly overlain by mudstones. At the type section, the sequences are made mainly of middle and outer fan sandstones, and overbank and basinal mudstones. The Tha Si Member comprises mainly overbank mudstone facies (T6). The Mae Dum Sandstone Member commences conformably with flat-based, massive-bedded sandstones (T2, Fig. 4.1 C) characteristic of a middle fan channel. It is overlain successively by stacked channel and levee sandstone facies (T3 -T4) with planar basal beds, and the outer fan sandstone or sheet sand of Facies T5 which is topped by basinal mudstones (T6) containing *Daonella* and *Paratrachyceras*, interpreted by Chonglakmani (1981) as deep marine fauna. The sheet sand can be followed laterally for a long distance along the Huai Mae Dum (Fig. 4.4 C). The Mae Dum Sandstone described above also represents an upward deepening megasequence. A similar megasequence also occurs in the upper part of the section along the Huai Muang, but the basinal mudstone portions seem to contain more intercalated limestones containing thin-shelled bivalves. The depositional basin shows upward-shallowing, toward the overlying platform limestones of Doi Long Formation. The shallowing-upward sequence also prevails in Ngao as gradational contacts from Hong Hoi mudstone to Pha Daeng red beds.

Although it has been suggested that cross-stratification yields less precise paleocurrent direction than sole marking (Walker, 1978; Miall, 1984), Powell (1990) showed that those in graded beds commencing with Bouma Ta or Tb generally give the same direction as from sole markings. Rare small scale cross-stratification in the Hong Hoi Formation suggests axial paleoflow, approximately NNE-SSW. To the north of the study area, the Triassic sequences (Baum and Hahn, 1977) are clearly unveiled along a new highway between Phayao and Wang Nua. There, the basinal facies is represented by laminated mudstone to clayshale with rare sandstone beds; they also display good lateral continuity of beds.

4.5 Facies relationships and depositional environments of Wang Chin Formation

The Wang Chin Formation, similar to the Hong Hoi Formation, consists mainly of middle-fan, outer-fan, overbank and basin plain sediments. Interpretation of depositional environments is based on the measured sections along the Rong Kwang-Ngao highway (Fig. 2.10) in the north, and along the Lampang- Denchai highway (Fig. 2.12) in the south.

In the north, the Wang Chin sediments show a facies change from the shallow-water deposits of the underlying Pha Daeng Formation (Fig. 2.10 D). They are mainly fine-grained sediments, representing overbank and middle submarine fan facies. They show the same paleocurrent directions as the underlying Pha Daeng red beds (see CH-5); the directions also correspond with eastward deepening of the sediments, as suggested by the presence of allodapic limestones between km 34.0-34.4 on the Rong Kwang- Ngao highway, and at Huai Chan.

To the south along the Lampang-Denchai highway, depositional environments were relatively deeper than in the north. Here the formation consists of middle-fan, overbank and basin plain sediments. The middle-fan channel-levee sandstones are stacked, and bounded by overbank and basin plain mudstones (Fig. 2.12). A middle-fan channel is recognized by the facies association of massive bedded sandstone (T2), turbidite sandstone (T3) and slump strata (T4) as shown in Figure 4.2. Asymmetric cycles such as upward-thinning are common (Fig. 4.5) and are indicative of channel environments; the laterally thinning beds in Figure 4.4 A support the interpretation. In many places, bivalves lie convex-side up and have a close association with thin to medium bedded sandstones; the bivalves were possibly deposited in overbank environments. The stacked sandstones are represented by the Mae Lu Sandstone Member and the mudstones by the Phu Tap Member (Fig. 2.12). Fossil data indicate that these stacked sandstones differ in age. Paleocurrent directions of the Wang Chin Formation from the Rong Kwang- Ngao highway, and the Lampang- Denchai highway are divergent, with the former pointing N and E while the latter points S, E and W. All point away from the present Upper Paleozoic outcrops. The opposite paleocurrent directions indicate a topographic high being present in that area, at least during the early Norian. This further suggests the existence of an emerging area, a view that is consistent with the study of the provenance of sandstones (for details see CH-6).

Chapter 5 : Facies and depositional environment of the Pha Daeng red beds

5.1 Introduction

The words Pha Daeng red beds and Pha Daeng Formation are interchangeable in this study. The red beds are exposed mainly in the upper half of the main study area (Fig. 2.1) and consist of sandstones, siltstones and mudstones with minor conglomerates. In general, their grain sizes decrease approximately northward consistent with the paleocurrent direction. Conglomerates are common in the southern part (Ban Tha Si and Long) and are rare in the northern part (Ngao and Song).

All previous published papers (e.g. Piyasin, 1972; Hahn, 1976; Bunopas, 1981; Chonglakmani, 1981; Helmcke, 1984; Chonglakmani and Helmcke, 1989) presumed the broad term "continental environment" for the Pha Daeng red beds, based mainly on oxidation characteristics. There have been no facies studies published. The Pha Daeng red beds, in fact, generally show part of a Bouma sequence displaying normal grading, even and parallel bedding with good lateral continuity and, in some places, are associated with emergence features. Extensive detailed examination in this study shows that the red beds accumulated in both subaerial and subaqueous conditions in a fan delta environment.

The purpose of this chapter is to clarify depositional environments and paleogeography of the Pha Daeng Formation, in particular the red beds. To this end, the facies of the Pha Daeng Formation are defined and paleocurrent directions are demonstrated.

5.2 Facies of the Pha Daeng red beds

The Pha Daeng Formation consists of five facies, defined on the basis of lithology, sedimentary structure and paleocurrent. Most of the rock exposures have steep dipping beds and poor lateral continuity which hamper lateral investigation.

Nevertheless, the sections studied (Figs. 2.8 and 2.10) were taken from northern and southern parts, representing both proximal and distal sedimentations in both the Lampang and Phrae sub-basins. The salient characteristics of the Pha Daeng facies are summarized in Table 5.1.

5.2.1 Facies F1 : Conglomerate association

The conglomerates of Facies F1 often display normal grading and structureless fabrics with subordinate graded-stratified fabric and rare reverse-to normally graded fabric. These polymictic granule to cobble conglomerates are matrix- to clast-supported within a matrix of sands. Clasts consist mainly of acid-volcanics, white vein quartz and red sandstones (which are generally similar in lithology to the matrix). Clasts in the structureless or unstratified conglomerates are normally bigger (> 20 cm) and less rounded than those in the stratified types (round to subround and normally < 10 cm). The conglomerates, in some instances, are separated by lenticular, laminated coarse-grained sandstones. The conglomerate unit may be 15-20 m thick.

The structureless conglomerate (Fig. 5.1 A) which lacks internal fabric orientation, commonly occurs in the lower part of Facies F1, and consists of very thick, non-parallel beds. It is poorly sorted and may display low angle erosional basal contacts. Overlying the structureless conglomerate is a crude-graded conglomerate that often contains imbricated structures (Fig. 5.1 C). The normally-graded conglomerate (Fig. 5.1 B) is thin- to thick-bedded. It commonly shows erosional basal contacts, and grades upward to sandstones. The coarse-tail graded fabric is common and characterized by the coarsest clasts occurring mainly in the lower part of a bed. It rapidly gives way upward to fine pebbles (Fig. 5.1 C) whereas distribution grading, in which the fabric shows grading throughout the bed from coarse to fine, is rare. The reverse-to normally-graded conglomerate, if present, is thin and often associated with normally-graded conglomerate. The graded-stratified conglomerate displays both cross-stratification and normal grading and is often associated with sandstones commonly displaying lamination.

Facies F1, in the measured sections, represents about 10 % of the Pha Daeng Formation. Currently it is mainly exposed in the middle part of the eastern flank of the Lampang and Phrae sub-basins (Fig. 2.10), as at Doi Pha Daeng, Huai Or Dong and at Huai Pha Bong which consist mainly of volcanic clasts.

Interpretation : The occurrence of unstratified, reverse-to normally-graded, normally-graded, and graded-stratified conglomerates of Facies F1 corresponds to downfan movement of gravity flows (Walker,1984), where the sediments decrease in concentration and become less cohesive away from the source.

Table 5.1 Summary of the salient characteristics of the Pha Daeng fan delta facies.

Facies	Grain size	Sorting	SS:MD ratio	SS/MD contact	SS bed thickness*	Bed form	Facies r/ship	Approx. expos. %	Sedimentary structures	Interpretation
F1 : Conglomerate association	granule cobble	poor- good	-	-	≤ 300 cm (cgl)	poor lat. continuity	F3	10	normal grading, structureless, channel, rare imbrication	proximal alluvial fan, channel fill, debris flow, grain flow
F2 : Limestone-clast conglomerates	granule-cobble	poor- good	-	-	≤ 100 cm (cgl)	poor lat. continuity	F3	5	normal grading, structureless, carbonate cement	proximal alluvial fan, channel fill, grain flow
F3 : Medium- to very thick-bedded sandstones	c sand	mod.-poor	>10	sharp, erosional	15- 200 cm	non-parallel	F1, F2	20	normal grading, rare mud capped, oxidation	proximal channel, grain flow
F4 : Maroon mudstone & interbedded turbiditic sandstone	f-m sand	good	1:1-1:3	sharp w low angle erosion	≤ 30 cm	planar, parallel	F5	40	Bouma seq.,	distal fan-delta, subaqueous, low conc. turbidity current
F5 : Mudstone with calcareous concretions	f sand	good	<1:3	sharp, erosional	≤ 20 cm	wavy, parallel	F4	25	calc. concretion, mudcracks, vertical burrow, mottling	shallow marine, overbank

* sandstone bed thickness except where specified.

Fig. 5.1 Photographs showing characteristics of Facies F1, F2 and F3.

A) Structureless conglomerate of Facies F1 displays poor sorting with abundant tabular clasts; Pha Daeng Formation at Huai Pa Nua, 6 km east of the Doi Pha Daeng. Camera cap is 5 cm in diameter

B) Normally graded conglomerate with coarse-tail grading (Middleton, 1967) (pen) of Facies F1 is interpreted as having been deposited as proximal channel-fill in fan-delta; Pha Daeng Formation, same location as Fig. 5.1 A.

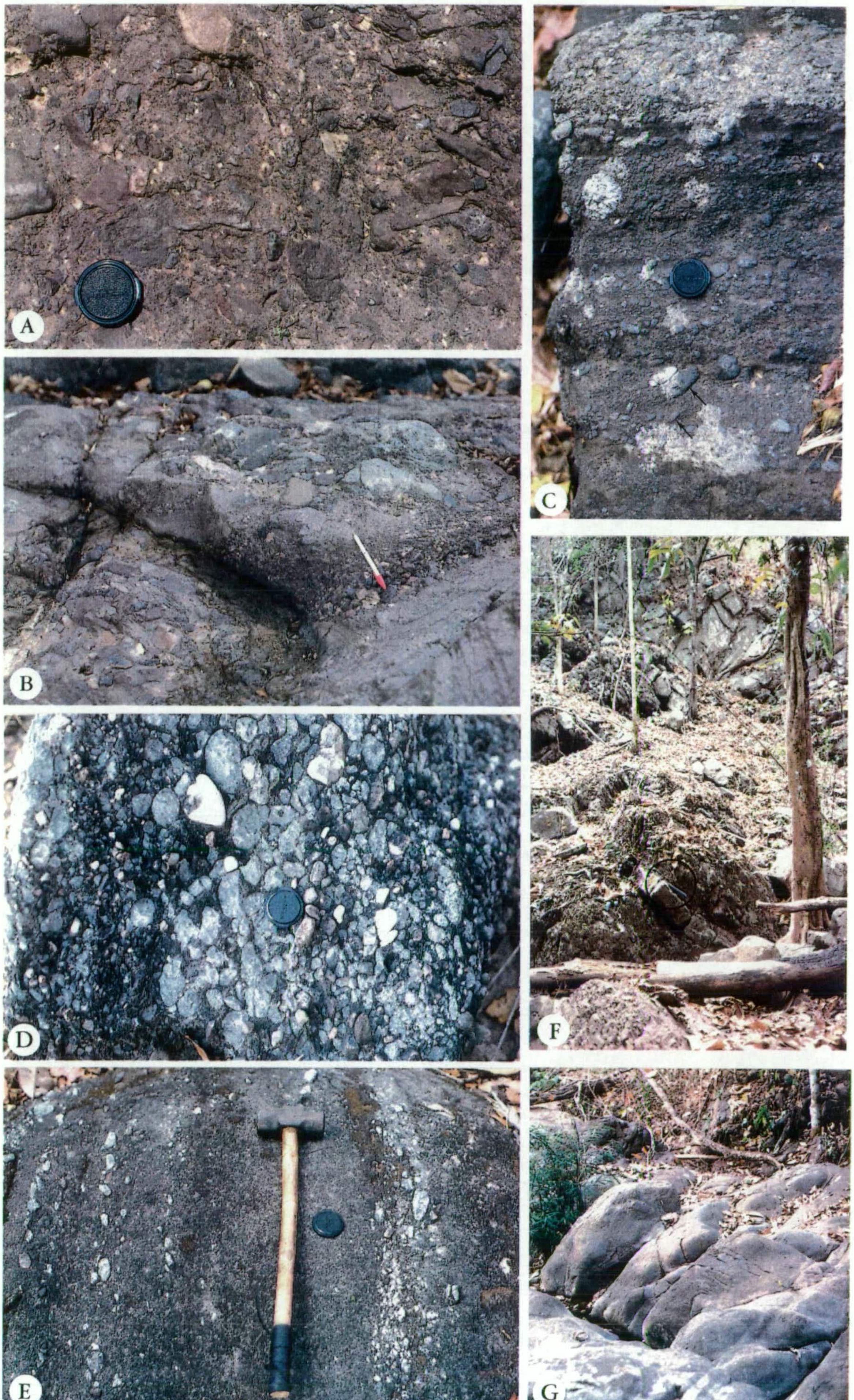
C) Crude normally graded conglomerate of Facies F1 with imbrication (arrow) indicating paleocurrent towards NNW; Pha Daeng Formation at Huai Pha Bong.

D) Limestone conglomerate of Facies F2 consists mainly of limestone-clasts, displaying normally graded bed and erosional basal beds (Beds young to right).

E) Coarse-grained sandstone of Facies F3 contains streaks of limestone pebbles, resulted from lateral facies variation with the limestone conglomerate of Facies F2; top to right. The rocks of this photo overly those in the Fig. 5.1 D. Camera lens cap is 5 cm in diameter.

F) Thickly-bedded, coarse-grained sandstone of Facies F3 (upper right) lying on maroon mudstone and siltstone of Facies F5 (at the hammer, circle). Note rapid facies change; Pha Daeng Formation at Huai Or Dong.

G) Very thick bedded (2 m), structureless, coarse-grained sandstone of Facies F3; Pha Daeng Formation at Huai Pha Bong.


A
B
C
D
E
F
G

The alluvial fan origin of Facies F1 is not only interpreted from its debris flow nature but also from its rapid facies change characteristics and the downfan decrease in grain size. The sheetflood sediments that are a diagnostic feature of alluvial fans have not been recognized in this study due to poor rock exposure. Poor sorting and structureless fabric in the matrix-supported conglomerate indicate formation by the debris flow process. The particles in debris flow are supported and carried away by their buoyancy and the cohesiveness of a sediment-water matrix (Pickering et al., 1986). The clast-supported conglomerates were interpreted as being formed by grain flow processes in which the clasts were maintained against gravity by dispersive pressure arising from clast collision (Lowe, 1982). The normally-graded conglomerate may have been formed by vertical sedimentation from a high density turbidity current while the graded-stratified conglomerate may partly have been deposited by traction sedimentation (Pickering et al., 1986). Although graded conglomerates overlain by laminated sandstones can occur in both fan delta and braid delta environments, the lenticular shape and the lack of cross stratification in sandstone favor the former environment. The laminated sandstones were formed by turbidity current and may have been deposited as a later separate event because sand in a turbidity current tends to outrun the gravel due to the contrasting grain-supported mechanism (Higgs, 1990) and because the sandstone basal contacts are not gradational.

Facies F1 probably accumulated partly under subaqueous conditions because: 1) well developed graded beds are common in subaqueous conditions but are rare in subaerial debris flows (Nemec and Steel, 1984), and 2) the interbedded sandstones lack cross-stratification and are more reminiscent of turbidites than stream flow deposits.

5.2.2 Facies F2 : Limestone-clast conglomerate

Facies F2, like Facies F1, displays a structureless fabric in the lower part (Fig. 2.9 D) with graded fabric increasing in frequency towards the upper part (Fig. 5.1 D) of the sequence. Facies F2 is clast-supported and most clasts are rounded consisting mainly of carbonates (granule to cobble, light gray and red in color), probably derived from the underlying formation (represented in this case by the Doi Long Formation), and based on these criteria it can be distinguished from Facies F1. Siliciclastic components (in terms of clast, matrix, and bed), particularly red sands, increase up the sequence (Figs. 2.8 A and 2.9 D). The sandstone-clast lithology is similar to the matrix. Beds show poor lateral continuity and often have sharp basal contacts. The lateral facies variation with sandstone of Facies F3 may be represented by thin layers of limestone pebbles (Fig. 5.1 E).

Facies F2 occurs locally and represents less than 10 % of the Pha Daeng Formation. It crops out at Doi Pha Bong (Fig. 2.10 A), and between Doi Pha Bong and Ban Ngiu Ngam, to the northeast. It has not been observed in the Huai Or Dong-Huai Nam Lon section nor in the Phrae sub-basin.

Interpretation : The roundness of the limestone clasts implies extensive transportation and interaction with current media, possibly water. The limestone clasts, based on their occurrence overlying platform limestones, their roundness, and the lithology of Facies F2, were possibly beach gravels. However, Facies F2 is not comparable to gravel beach deposits because the prominent sedimentary features of such deposits such as imbricated structures and disc-shaped clasts (Postma and Nemec, 1990) are rare in Facies F2. Rare cross-stratification in the associated sandstones of Facies F3 supports this interpretation. This evidence in conjunction with lithology of Facies F2 further suggests that the beach gravels were later resedimented subaqueously downslope by grain flow processes to form Facies F2. The occurrence was initially far away from clastic influences. The cause of movement was possibly earthquakes. Vertical facies variation from unstratified to stratified limestone-clast conglomerates correspond to downslope changing of gravity flow sediments where more water was added to the system.

5.2.3 Facies F3 : Medium to very thick-bedded sandstone

Facies F3 sandstone is red, light-gray, coarse- to fine-grained, medium- to very thick-bedded (mode 15-100 cm thick, in rare cases up to 200 cm), and wavy and non-parallel bedded, often displaying positive grading, except in the very thick beds (Figs. 5.1 F, G). It has both sharp and erosional basal contacts. It may be intercalated with thin-bedded, fine-grained, micaceous maroon sandstone, and capped by red mudstone. The sandstone to mudstone ratio is greater than 10. Facies F3 normally rests on Facies F1 and F2, and grades upward to the interbedded sandstone and mudstone of Facies F4, as at Huai Nam Lon. Lateral facies variation with coarser facies may be represented by granule streaks in sandstones (Fig. 5.1 E).

Facies F3 represents about 20 % of the Pha Daeng Formation in the measured sections (Fig. 2.10). It rests on top of Facies F1 at Huai Pha Bong and Huai Or Dong, and Facies F2 at Doi Pha Daeng.

Interpretation : Very thick-bedded sandstones are well represented in many grain flow sequences where the fluid concentration is high, and commonly occur as channel deposits (Walker, 1984; Postma, 1986). Interpretation of channel deposits, possibly proximal, is supported by its wavy and non-parallel beds and close association with Facies F1 and F2. The normal-graded beds are believed to be created by the suspension load of a low-concentration turbidity current where the concentration is decreasing. Although red coloration in red beds is believed to be a product of diagenesis (Turner, 1980; Collinson, 1986), almost all documented red beds belong to shallow water environments. This facies is interpreted in the same way.

5.2.4 Facies F4 : Maroon mudstone and interbedded turbiditic sandstone

Facies F4 is characterized by maroon mudstone (texturally may be siltstones) and interbedded turbiditic sandstone (Figs. 2.9 F and 5.2 A). The sandstone to mudstone ratio ranges from 1:1 to 1:3. Beds are wavy to parallel in type, and display good lateral continuity. The maroon mudstone is laminated to thick-bedded, having both gradational and abrupt basal contacts, and generally abrupt upper contacts. The sandstone, typically gray and grayish-green but also red or maroon, is fine- to medium grained, thin- to medium-bedded, and commonly displays part of the Bouma sequence (Fig. 5.2 B). Positive grading and lamination are the most common structures, while small-scale and asymmetrical cross-stratifications (Fig. 2.9 I) occur locally. Flute structures are rare; if present they are small. Plots of foresets of the cross-stratification show a unimodal paleocurrent direction. Facies F4 usually overlies Facies F3 and underlies Facies F5 which often contains mudcracks and vertical burrows.

In the measured sections, Facies F4 represents about 40 % of the Pha Daeng Formation (Fig. 2.10). It is well exposed between approximately km 50.7 and 61 on the Rong Kwang-Ngao highway, and along Huai Nam Lon.

Interpretation : According to Walther's Law, a vertical sequence changing from Facies F1 (or F2) through to Facies F3 and F4 implies successive distal sedimentation equivalent to Facies F1 (or F2). Distal fan sedimentation of Facies F4 is consistent with its grain size, which decreases downfan, and with the paleocurrent directions. Turbidites are a subaqueous phenomenon (Table 5.2). The characteristics of good lateral continuity of beds, rare channel structures and cross stratifications, and having turbidite origin of Facies F4 imply subaqueous sedimentation from a low concentration turbidity current under an unconfined conditions. Beds of good lateral continuity with sharp bases are common in alluvial fan sheetflood deposits (Collinson, 1986, p 50). The combination of red coloration and close association with the mudcracks, gray mottlings and vertical burrows of Facies F5 suggests shallow water origin for Facies F4.

Fig. 5.2 Photographs displaying features of Facies F4 and F5.

A) Facies F4 is characterized by parallel bedded, fine to medium-grained sandstone (lighter beds) and interbedded maroon mudstone. Small displacement of west-directed thrust fault; Pha Daeng Formation at km 61+050 m on the Rong Kwang-Ngao highway; hammer as a scale.

B) Bouma Tbcde in maroon fine-grained sandstone and siltstone of Facies F4 which is closely associated with mudcracks (Figs. 5.2 C&D) indicating shallow water origins; Pha Daeng Formation at Huai Nam Lon (coin is 2.7 cm in diameter).

C & D) Mudcrack-cast on sandstone basal bed of Facies F5; Pha Daeng Formation at Huai Nam Lon.

E) Facies F5 showing maroon and green mudstones and interbedded sandstone; the maroon and the green mudstones commonly display gradational contacts; Pha Daeng Formation at km 45+335 m on the Rong Kwang-Ngao highway.

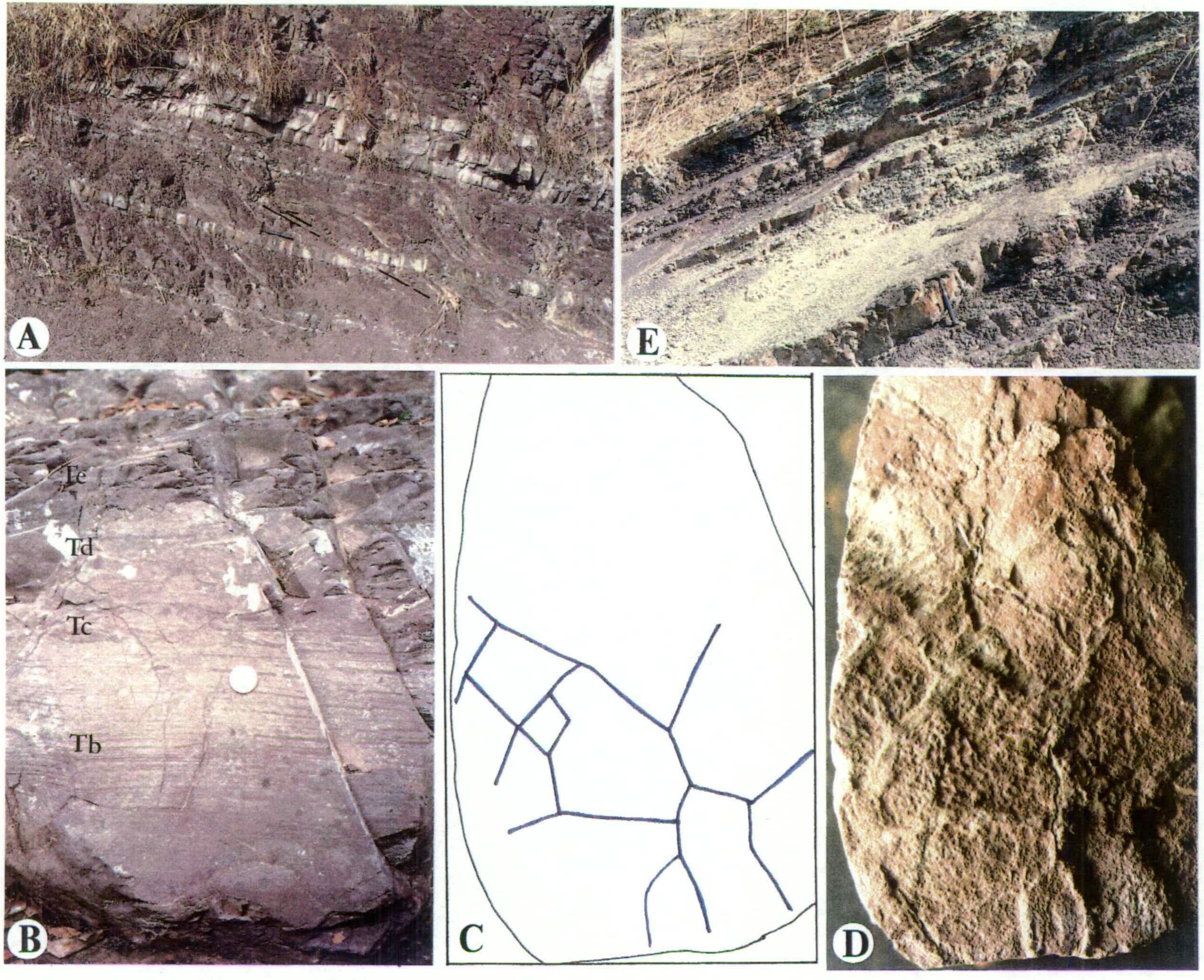

A
E
Te
Td
Tc
Tb
B
C
D

Table 5.2 Some characteristics of subaerial and subaqueous debris flows

Characteristics	Subaqueous debris flows	Subaerial debris flows	References
Graded beds	Common	Rare	Nemec et al.,1980; Rust & Koster ,1984; Higgs, 1990
Lateral accretion	uncommon	common	Bouma & Coleman ,1985; Wuellner & James, 1989
Bth/MPS	7:1 (range 3:1 - 10:1)	<4:1	Nemec et al.,1980
Sorting	Good- poor	Poor	
Sandstone X-stratification	Uncommon	Common	Higgs, 1990
Viscosity	Low-high	High	Ballance, 1984
Imbrication	Common	Absent	Ballance, 1984
Thinning & fining-up cycles	Common	Uncommon	
Fossils, wood fragments	?Common	Rare	
Oxidation	Uncommon	Common	

Walker (1984, p 172), however, noted that to preserve sedimentary structures created by turbidity currents, deposition must take place below the effective wave base because they may be destroyed by subsequent waves and currents. Neither bimodal current nor storm evidence has been observed. The depth of the storm wave base varies depending on climate, size of the depositional basin and topography. The depth of 204 m in winter and, generally, less than 85 m in summer were recorded (Johnson and Baldwin, 1986).

As mentioned in 5.2.3, most known red beds have shallow water origins, although red coloration is believed to be a result of diagenesis (Turner, 1980; Collinson, 1986). The difference in color between red or maroon mudstone and siltstone and interbedded gray sandstone in Facies F4 is possibly caused by the effects of diagenesis due to the finer fractions containing more iron hydroxides than the coarser fractions (Turner, 1980).

Similar maroon turbidites, associated with mudcracks, were recognized by Ballance (1984) in non-marine Middle Cenozoic gravel-dominated fan-deltas that filled in half-grabens associated with the San Andreas fault system of California. He interpreted his parallel-bedded, graded sands facies, often displaying Bouma sequence, rip-up clasts and mudcracks, as having been deposited in the distal part of a lake.

5.2.5 Facies F5 : Mudstone with calcareous concretions

Facies F5 is characterized by alternations of mudstone, sandstone and siltstone and often contains round calcareous concretions. The sandstone to mudstone ratio is less than 1:3. The concretions are normally 1 to 3 cm in diameter (reaching 20 cm) and lie parallel to the bedding plane. Mudcracks (Figs. 2.9 G, 5.2 C, D), vertical burrows, gray mottling and small-scale cross-stratifications occur locally. Mudstones are mainly maroon but can also be green (Figs. 2.9 G, 5.2 E). ~~Coalitized~~ Coalified wood fragments are often observed in green mudstone. Sandstone is maroon, grayish-green, normally fine-grained, thin- to medium and wavy bedded, often showing good lateral continuity of beds, normal grading, and sharp basal contacts. Plots of foreset from cross-stratification indicate unimodal paleocurrent direction.

Facies F5 is exposed largely in the trough of the "Tha Si Syncline" and in the northern part of the Phrae sub-basin.

Interpretation : This facies is conformably overlain by gray mudstones containing early middle Carnian marine benthic fauna, *Palaeocardita singularis* (at km 45.4 on the Rong Kwang-Ngao highway) and platform limestone sequences (in SW of Ngao area) of Kang Pla Formation. Since Facies F1 through F4 have been interpreted as being mainly subaqueously deposited, this evidence suggests that the aqueous conditions for the Pha Daeng fan deltas was shallow marine. Occurrence of mudcracks, calcareous concretions, maroon color, gray mottlings and vertical burrows all support shallow water conditions. The first three occurrences also indicate subaerial exposure. In addition, the interbedded gray, green and maroon mudstones are common in shallow marine shelf environments. Similar occurrences are reported from overbank facies elsewhere (Allen, 1983; Miall, 1985). Occurrence of the concretions parallel to bedding planes may be due to differences in permeability and composition between beds(Collinson and Thompson, 1982, p 152).

5.3 Evidence from paleocurrent analysis

Cross-stratification is the only paleocurrent indicator available in the Pha Daeng red beds and is not common. It is small-scale and more abundant in fine-grained sandstone and siltstone. Paleocurrent directions were mostly determined in three areas: Huai Or Dong (loc. 1 of Fig. 5.3) to Huai Nam Lon (loc. 2), km 51- 62 (loc 4-6) and km 39 (loc. 7-8) on the Rong Kwang-Ngao highway. In addition, single to few paleocurrent measurements from several localities were also obtained to reconstruct the paleoflow of the Pha Daeng red beds (Fig. 5.3). The restoration of the original attitude of cross-bedding data from tectonically inclined beds follows the procedure of Collinson and Thompson (1982).

Although paleocurrent directions obtained from trough cross-beds have been noted yielding less accuracy (Walker, 1978; Miall, 1984), the directions in the Pha Daeng red beds are rather consistent. Paleocurrent directions in Lampang and Phrae sub-basins are almost parallel, suggesting that the sediments in these two sub-basins were derived from different places and deposited in different basins. This supports the "Adjacent basin model" proposed in section 2.2. Paleocurrent directions of the proximal facies of both the Lampang (loc. 1, 4, Fig. 5.3) and Phrae (a point south of loc. 10) sub-basins show transverse paleoflows, towards the northwest to the paleobasin axes, whereas most distal facies (e.g. loc. 2, 5, 6, 10) display mainly axial paleoflows. A change from proximal to distal sedimentation is reflected in the paleocurrent directions and the decreasing grain size. Axial paleocurrent flows possibly followed the axis of maximum tectonic subsidence.

In the Phrae sub-basin, at least two fan deltas are suggested by the paleocurrent directions. One is from locations 7 and 8, the other from locations 9 and 10. At locations 7 and 8, the directions indicate continuous sedimentation from red beds (loc. 7) to gray turbidites (loc. 8) which possibly have the same provenance. Continuous sedimentation from red beds to allodapic limestone with the possibility of the same source area is suggested from paleocurrent directions of location 10 and 9, respectively. Note that locations 8 and 9 belong to the Wang Chin Formation.

5.4 Facies association and depositional environments of the Pha Daeng fan delta: interpretation

Fluvial environments are not consistent with the Pha Daeng red beds due to the paucity of channel and lateral accretion structures. The Pha Daeng red beds, in fact, are compatible with fan delta sediments, on the basis of their characteristics of gravity flow sediments, sheet flood deposits, rapid facies changes and poor sorting, decreasing grain size down stream and subaqueous sedimentation. The fan delta is an alluvial fan that builds into standing water from an adjacent highland (Holmes, 1965; McPherson et al., 1987, 1988). Nemec and Steel (1988) stressed the element of mainly or entirely subaqueous sedimentation in that fan delta definition.

As interpreted here, the Pha Daeng red beds facies were mainly subaqueously deposited, specifically in a shallow marine environment. There is, however, no depth indicator to suggest how shallow the environment was. Nevertheless, there are no bimodal currents to indicate tidal sedimentation. The absence of hummocky cross stratification suggests that there was little storm influence. The occurrence of local mudcracks indicates some emergence. The aqueous condition may be shallow marine

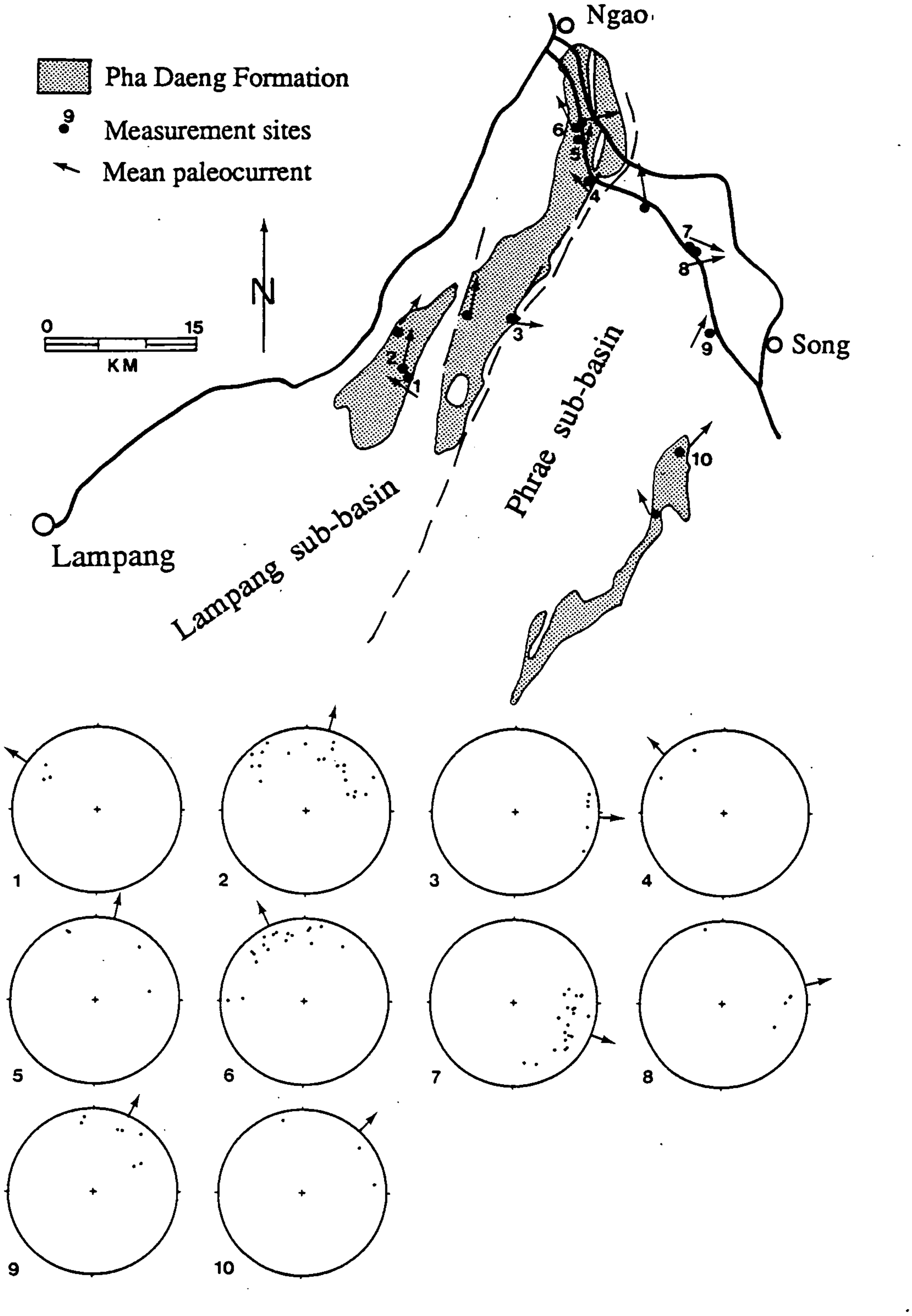


Fig. 5.3 Mean paleocurrent directions (arrow) of the Pha Daeng Formation. Cross-stratifications, after correction for tectonic tilt, are plotted as dots of trend and plunge of lines on a stereonet. An arrow (on a circle surface) represents the mean direction vector calculated by computer. The arrow (on the map) without a contiguous number represents a single paleocurrent measurement. Note that the locations 8 & 9 belong to the Wang Chin Formation. 1 = Huai Or Dong, 2 = Huai Nam Lon, 3 = Huai Mae Tip Noi, 4 = km 51.4, 5 = km 53.9, 6 = km 56, 7 = km 36.2, 8 = km 34-35, 9 = Huai Chan, and 10 = Doi Dong.

as suggested by the conformably overlying marine strata (fossils, limestones) and by the lithofacies of the red beds. Higgs (1990) showed that most deep-sea fan deltas developed when the sea-level was at least 100 m above the present sea-level. Sea-level during the Triassic Period, however, was generally below that level (Reading, 1986). Hence, the Pha Daeng fan deltas were probably of shallow-water origin.

Table 5.3 is from McPherson et al. (1987) showing salient characteristics of fan deltas against braid deltas. In general, fan deltas are distinguished from braid deltas by their distinctive features in the subaerial portion consisting of alluvial fan characteristics, i.e. gravity and sheetflood sediments, facies assemblages, paleocurrents and depositional geometry, while the braid delta consists of braided river sediments, e.g. common channel structures and cross stratifications (McPherson et al., 1987). Such characteristics of braided river sediments are rare in the Pha Daeng red beds.

In the measured sections (Figs. 2.8, 2.10), the Pha Daeng facies display mainly upward fining sequences. At least two megasequences were observed in the Huai Ting Tue, Huai Or Dong-Huai Nam Lon and Huai Pha Bong sections (Figs. 2.8 A, B and E, respectively). The basal part of the sequences generally consists of the conglomerates of Facies F1 or F2 (Fig. 5.4) and changes upward to the sandstones of Facies F3, and the interbedded sandstone, siltstone and mudstone of Facies F4 and F5. Following Walther's Law, the vertical facies changes from Facies F1(or F2) through F5 can be interpreted as successive distal deposits equivalent to Facies F1(or F2). Paleocurrent directions suggest that sediments were mainly derived from the south. The paleocurrent directions are consistent with grain size distribution. Conglomerates are common in the southern part of the exposures (Fig. 5.3; at Doi Pha Daeng, Huai Or Dong, Huai Pha Bong) and are rare in the northern part where fine-grained sandstone, siltstone and mudstone are predominant.

The presence of alluvial fan facies is generally taken as direct evidence for the placement of an active vertical movement in which the higher areas were rapidly denuded, providing sediments to the lower areas where the fan was forming. Paleocurrent directions further suggest that there were a number of sedimentary basins, at least two, lying parallel to each other and to the main structural trends (e.g. volcanic trend). Fan deltas consisting mainly of fining upward sequences indicate occasional or sporadic tectonic activities that created non-progradational fans. The occurrence of predominantly fine-grained sediments may be partly caused by climate and source rocks. Lack of evaporites in the Lampang Group suggests the climate was not arid, thus possibly humid. Paleomagnetically, the Shan-Thai terrane during the Triassic was placed in low latitude tropical areas. Alluvial fans, on the other hand, are less common in humid tropical settings due to the predominance of climatically induced chemical weathering over mechanical production of coarse detritus, and

Table 5.3 Generalized characteristics of fan deltas and braid deltas (from McPherson et al., 1987)

Characteristics		Fan-delta	Braid delta
Tectonic setting		Active (synorogenic)	Active and passive
Physiographic setting		Fault blocks, mountain fronts, and volcanic highlands	Braided rivers, braided plains, and fluvioglacial outwash
Paleocurrents		Semi-radial and complex	Unimodal and simple
Depositional environments and processes	Subaerial	Sediment gravity flow Debris flows Mudflows Landslides Transitional flows Streamflows (confined and nonconfined) Sheetflood	Streamflows Braided channels Sheetflood (minor)
	Subaqueous	Marine and lacustrine Tides Waves Density flows Sediment gravity flows Suspension setting	
Subaerial lithofacies		Conglomerates and breccias (clast- and matrix-supported) Sandstones (minor) Mudstones (mudflows) Gms, Gm, Gh (minor Gt, Gp, St, Sh, Sp)	Conglomerates (clast-supported) Sandstones Gm, Gh, Gt, Gp, St, Sp, Sh
Maximum grain size		Boulders and cobbles very common	Boulders and cobbles uncommon
Sorting		Poor, grading uncommon	Moderate- good, grading common
Clast shape		Angular- subrounded	Subrounded- rounded
Subaerial profile		Very steep	Steep- moderate
Facies changes (vertical and lateral)		Complex, numerous, sharp	Simple, few, and gradational
Lateral continuity		Low	Moderate- high
Fossils		Plants, spores, pollen and vertebrates; marine and lacustrine fossils	
Soils and oxidation		Common	Uncommon
Geologic occurrence		Common	Very common
Geometry and size		Wedge and lenticular, tens of km^2 or less	Sheet, up to hundred of km^2
Reservoir quality		Poor	Good- excellent

protection of slopes by dense vegetation (Rust and Koster, 1984). Compositionally, the Pha Daeng red beds consist mainly of volcanic derived detritus that are mainly unstable elements. It can be concluded from the above conditions that a tropical humid climate and volcanic source rocks, as one would expect for the Pha Daeng depositional conditions, may provide inactive fine-grained fan deltas.

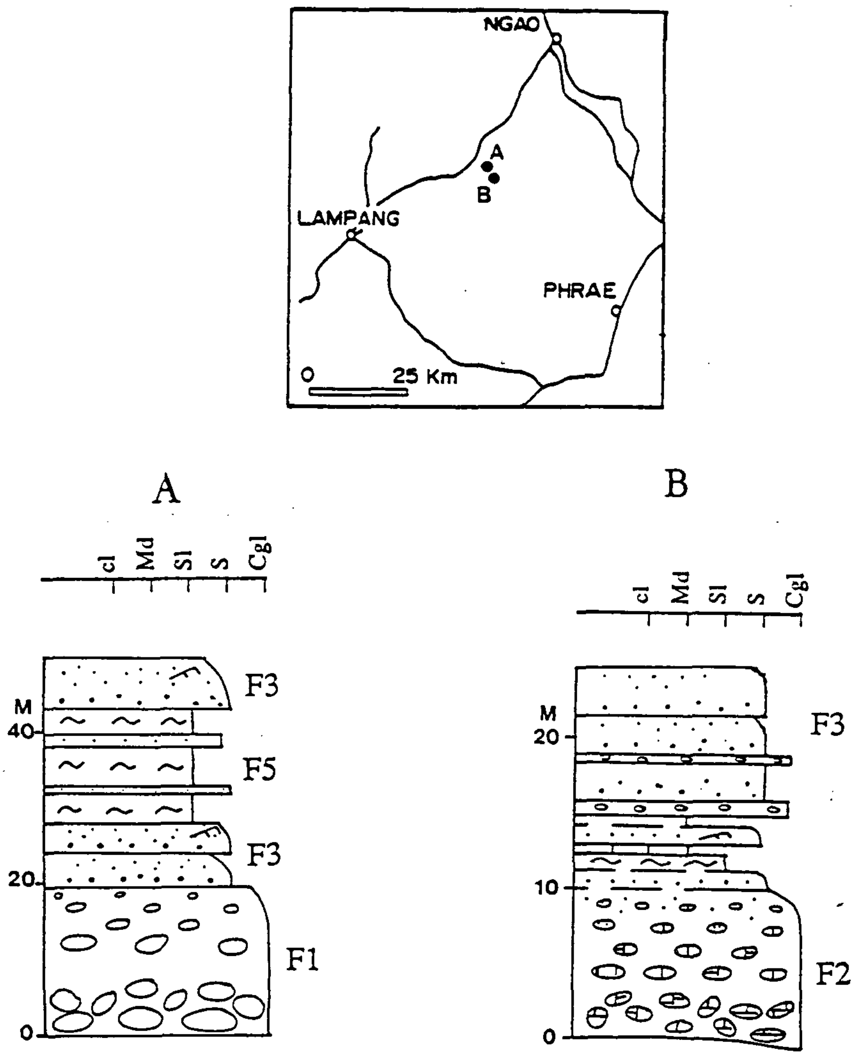


Fig. 5.4 Some fining upward sequences of Pha Daeng red beds; A) conglomerates with graded beds in the upper part of Facies F1, overlain by medium to thick bedded and graded sandstone of Facies F3, topped by mudstone and siltstone of Facies F5. The uppermost part of this figure is from Fig. 5.1 F, B) limestone-clast conglomerate of Facies F2 changes upward to sandstone of Facies F3, at Doi Pha Daeng.

Chapter 6 : Petrography, chemical composition and provenance of Lampang sandstones

6.1 Introduction

The compositional and chemical variation of sandstone is useful not only as a provenance indicator but also in the reconstruction of paleotectonic and paleogeographic environments (Dickinson, 1970; Pettijohn et al., 1987; Crook, 1974; Folk, 1974).

The relationship of sandstone composition with those sedimentary basins associated with plate tectonics has been well established by Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Valloni and Zuffa, 1984; Valloni and Mezzadri, 1984; and Dorsey, 1988, using ternary plots of framework modes. Of particular importance are QFL, QmFLt, QpLvmLsm and LmLvLs diagrams (for definition of grains see Table 6.1). The QFL and QmFLt diagrams can be used to distinguish provenances, which are subdivided into three main types: magmatic arc, continental block and recycled orogen provenances (Dickinson and Suczek, 1979; Dickinson, 1988). The QpLvmLsm and LmLvLs diagrams can also discriminate tectonic settings and provide more details (Graham et al., 1976; Ingersoll and Suczek, 1979). In addition, the proportion of grain types such as plagioclase to total feldspar (P/F), polycrystalline aphanitic quartz to total quartz (Qp/Q) and volcanic aphanitic fragments to total lithic aphanitic fragments (Lv/L) have also been regarded as essential criteria for discriminating tectonic settings (Ingersoll et al., 1984; Valloni and Zuffa, 1984; Dickinson, 1985; Lash, 1987).

The general validity of these diagrams and ratios has been confirmed by subsequent work on modern deep sea sands (Dickinson and Valloni, 1980; Maynard et al., 1982; Suczek and Ingersoll, 1985; Valloni and Mezzadri, 1984) and on known ancient sands (Dickinson, 1982; Dickinson et al., 1983; Valloni and Zuffa, 1984; Lash, 1987; Dorsey, 1988). Limitations of the approach include consideration of sandstones deposited in the transition between tectonic regimes, compositions that are more quartzose, and sandstones found in settings unrepresented on the diagrams (Mack, 1984; Velbel, 1985; Lash, 1985). Dissolution of detrital grains is not a major obstacle to this approach, since their grain boundaries often remain and are able to be identified (Dickinson, 1970).

The abundances and ratios of rare earth elements (REE) obtained from turbidites have been used to aid in the reconstruction of tectonic settings of depositional basins (Bhatia, 1985; Floyd and Leveridge, 1987) because they exhibit insignificant changes during sedimentary processes. Lampang sandstones are mostly immature, of turbiditic origin and have undergone only little alteration, which make them ideal for these kinds of studies.

It has been suggested widely that chemical properties of detrital feldspar can be used to aid in determining provenances (Trevena and Nash, 1981; Helmold, 1985; Pettijohn et al., 1987). However, this method is not confirmed in this study.

The purpose of this chapter is to reconstruct provenance composition and paleotectonic environments for sandstones of the Lampang Group using both petrographic and geochemical data.

6.2 Method for modal analysis and grain parameters

Two different counting methods were employed here. Names of sandstones follow the sandstone classification of Folk (1974) while detrital modes for provenance and paleotectonic studies were point-counted by the Gazzi-Dickinson method detailed by Ingersoll et al. (1984). The latter method is able to minimize the effect of grain size on composition and differs from the former in that it typically counts sand-sized crystals and grains within larger fragments as a category of the crystal or grain rather than as the category of the larger fragment (Dickinson, 1970; Ingersoll et al., 1984; Suttner and Basu, 1985). For example, a sand-sized plagioclase phenocryst within a volcanic rock fragment is counted as plagioclase; a sand-sized rutile in quartz or a sandstone rock fragment is counted as a rutile grain; and a sand-sized quartz crystal within a lithic fragment is counted as quartz. Although the nomenclature of single detrital grains in these two methods is similar, all the names of lithic fragments after the Gazzi-Dickinson method should contain the word "aphanitic", and on this basis they can be distinguished from the "traditional method" (e.g. Folk, 1974; Pettijohn et al., 1987).

A minimum of 400 points was counted per thin section. Only samples constituting less than 25% matrix and grain size bigger than 0.06 mm were considered for analysis. In order to minimize the error caused by limitation of the identified area, the maximum spacing (about 350 μm) of the point counter was used.

Table 6.1 Definition of grain parameters.

Q	= Qm+Qp	Where	Q	= total quartzose grains
			Qm	= monocrystalline quartz
			Qp	= polycrystalline aphanitic quartzose grains including chert
F	= P+K	Where	F	= total feldspar grains
			P	= plagioclase feldspar grains
			K	= potassium feldspar grains
L	= Lm+Lv+Ls	Where	L	= total unstable aphanitic lithic grains
			Lm	= metamorphic aphanitic lithic grains, including schistose mica
	Lv=Lvm		Lvm	= volcanic, metavolcanic and hypabyssal aphanitic lithics (microlitic, lathwork, felsitic and vitric types)
	Ls = Lss		Lss	= silicic sedimentary aphanitic lithic grains
	Ls* = Lss+Lsc		Lsc	= carbonate sedimentary aphanitic lithic grains
Lt	= L+Qp	Where	Lt	= total aphanitic lithic grains plus polycrystalline aphanitic quartzose grains
Lsm	= Ls+Lm	Where	Lsm	= sedimentary and metasedimentary aphanitic lithic fragments
			MC	= matrix and cement
			H	= heavy minerals
			U	= miscellaneous and unidentified

Ls* only used for the Pha Daeng Formation

The grain parameters used in this study are defined in Table 6.1, following the guidelines of Dickinson (1970) and Ingersoll and Suczek (1979) who also provide useful criteria for recognizing detrital grains. The point-count data for each set of the ternary plot were recalculated to 100%. A brief description of each grain types is given below.

Recognition of *monocrystalline quartz* (Qm), *plagioclase* (P) and *potassium feldspar* (K) is straightforward when facilitated by the staining method (Norman, 1974). *Polycrystalline aphanitic quartz* (Qp), including chert, is a monocrystalline aggregate of mono-mineralic quartz in which most domains are smaller than 0.03 mm and have sutured subgrain contacts. *Volcanic* and *hypabyssal aphanitic grains* are grouped together as Lv. Microlitic, felsitic and lathwork textures are predominant in volcanic rock fragments. *Metamorphic aphanitic grains* (Lm) are mainly schistose mica with subordinate quartz-schist and phyllitic schist. Microscopically, these include aggregations of mica, feldspar and/ or quartz with or without preferred planar fabric. *Sedimentary aphanitic lithic grains* (Ls) of the Lampang sandstones include mudstone (Lss), shale (Lss), siltstone (Lss) and carbonate (Lsc). Mudstones are characteristically murky-looking, dark brown and gray, having a massive fabric with scattered silt subgrains. Shales differ from mudstones in their planar fabric orientation. Incompetent sedimentary rock fragments are often squeezed into interstitial pores and are elongated parallel to the bedding plane. Carbonate grains are not considered for analysis (Dickinson and Suczek, 1979) except in the Pha Daeng Formation where extrabasinal origin is clear, and where they can be used to aid in reconstruction of tectonic uplift (see Mack, 1984; Ingersoll et al., 1987).

Fifty-six sandstone thin sections were point-counted. Most were polished and stained (Norman, 1974) to aid in identification of plagioclase, potassium feldspar and quartz. These samples can be subdivided into five from the Phra That Formation, twenty-three from the Hong Hoi, thirteen from the Pha Daeng, and fifteen from the Wang Chin Formation. Thin section numbers preceded by LSM, SSM and USM were kindly provided by Associate Professor Suphachai Junhavat (for details see Junhavat and Asnachinda, 1987).

6.3 Petrography and provenance of the Lampang sandstones as revealed by detrital grains

Petrography and provenance interpretation of sandstones from four formations, in ascending order the Phra That, Hong Hoi, Pha Daeng and Wang Chin, are detailed below.

6.3.1 Petrography and provenance of the Phra That sandstones at km 31.7-31.9

Sandstones at km 31.7-31.9 on the Lampang-Denchai highway are mainly sublitharenite (Folk, 1974), moderately sorted and grain-supported, consisting mostly of quartz and minor volcanic rock fragments (Fig. 6.1 A). Quartz is predominantly monocrystalline and rounded, having undulose extinction and long-grain contacts. Quartz overgrowths and polycrystalline quartz (Folk, 1974) are common. Volcanic rock fragments are rounded, displaying mainly felsitic fabrics with rare feldspar phenocrysts. The sandstones are slightly sheared as suggested by oriented muscovite. The sandstones at this location contrast in lithology to the "type section" at Phra That Muang Kham temple which are quartz-rich litharenites consisting of volcanic fragments, sedimentary fragments, feldspar and quartz.

On the QFL diagram the Phra That sandstones fall in the recycled orogen field and on the QmFLt diagram they plot at the edge of the recycled orogen provenance field close to the Qm pole (Figs. 6.2 A, B; Table 6.2), suggesting that the ultimate sources were cratonic (Dickinson et al., 1983). Sediments of most quartzose rocks have multicycle origin (Dickinson, 1988). Such a multicycle origin for the Phra That sandstones are suggested by their common detrital quartz overgrowths, quartzose composition, mature texture and good roundness. Quartz overgrowths also imply sedimentary sources (Tucker, 1981). Some may have been derived from volcanic sources as indicated by volcanic fragments. Rock sequences at this location, based on their bimodal paleocurrent directions, close association with coal, channel structures and fining upward sequences, may have been deposited in tidal environments. Channel environments may also enhance sandstone maturity. The QpLvmLsm and LmLvLs diagrams are not applied for the Phra That sandstones since they contain less than 10% lithic fragments and have mature textures (Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979).

Fig. 6.1 Photomicrographs of sand grains from Phra That and Hong Hoi Formations

A) Typical view of sublitharenite with abundant rounded undulose monocrystalline quartz (Qm) and minor Qp and Lv. Phra That Formation at km 31.7, Lampang-Denchai highway; XP, stained thin section. Bar scale is 300 microns. Field sample no PL603 (details see Fig. 2.4 E).

B) Typical view of lithic arkose with abundant plagioclase (red), subordinate volcanic fragments (gray) and minor quartz (white). Note typical bipyramidal volcanic quartz. Huai Muang Member of Hong Hoi Formation at Huai Mae Dum; PL, stained thin section. Bar scale is 300 microns. Field sample no PL 357 (details see Fig. 2.6 A).

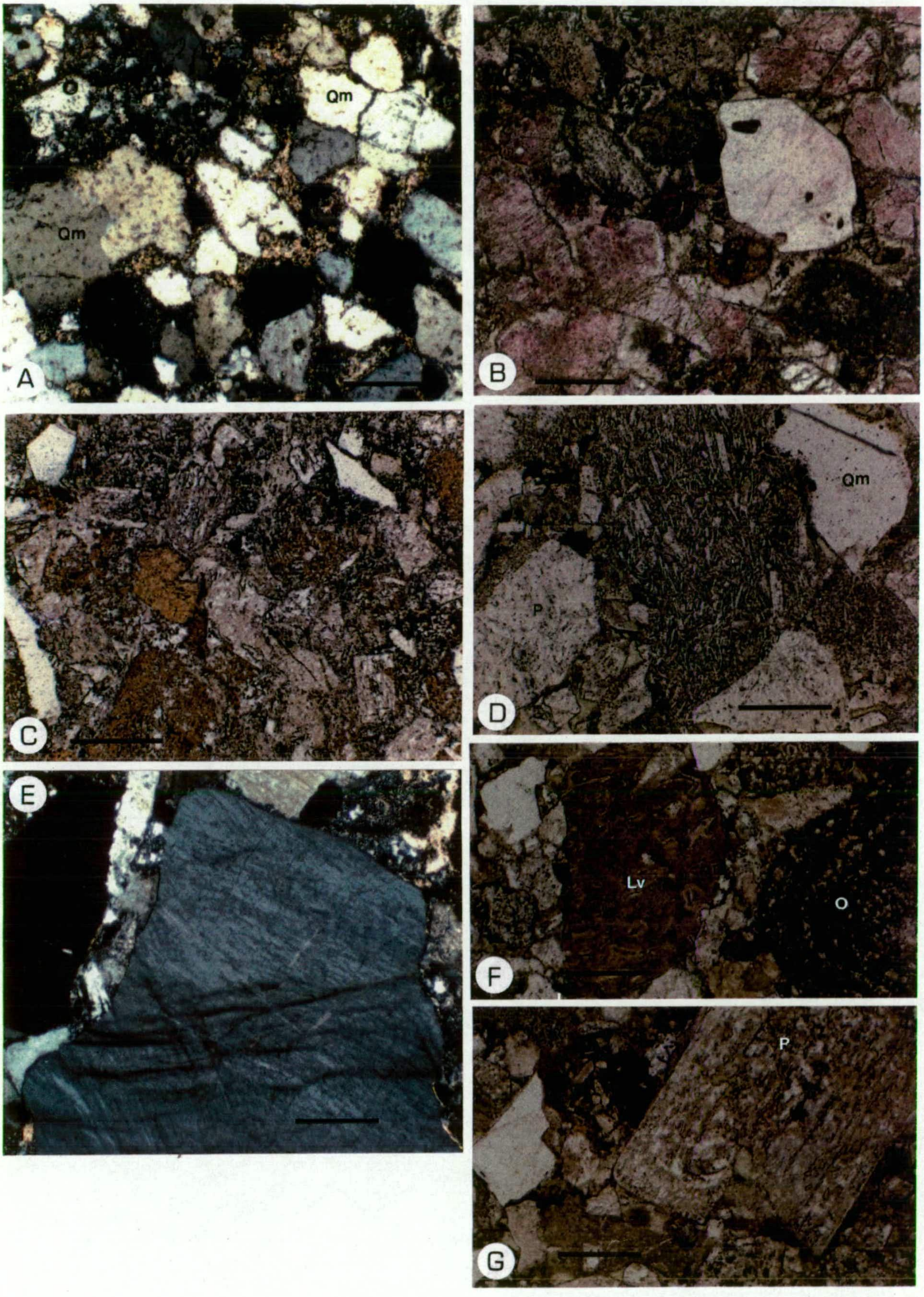
C) Lithic arkose of the Mae Dum Sandstone Member, at Huai Mae Dum, displaying plagioclase (red), potassium feldspar (solid yellow), volcanic fragments and angular quartz; PL, stained thin section. Bar scale is 200 microns. Field sample no PL354 (details see Fig. 2.6A).

D) Feldspathic litharenite from Mae Dum Sandstone Member showing microlitic volcanic fragments (Lv), plagioclase (P) and quartz (Qm); PL. Bar scale is 200 microns. Field sample no PL371 (details see Fig. 2.6 A).

E) Boehm lamellae in quartz from the Mae Dum Sandstone displaying two strain directions; XP. Bar scale is 300 microns. Field sample no PL353 (details see Fig. 2.6 A).

F) Volcanic aphanitic fragment (Lv) and ooid fragment (O); Hong Hoi Formation at Huai Muang. Bar scale is 300 microns. Field sample no PL 476 (details see Appendix B).

G) Oscillatory zoning in blocky plagioclase (P), an indicator of volcanic feldspar; PL. Same location as Figure 6.1 F. Bar scale is 300 microns. Field sample no PL476 (details see Appendix B).


A
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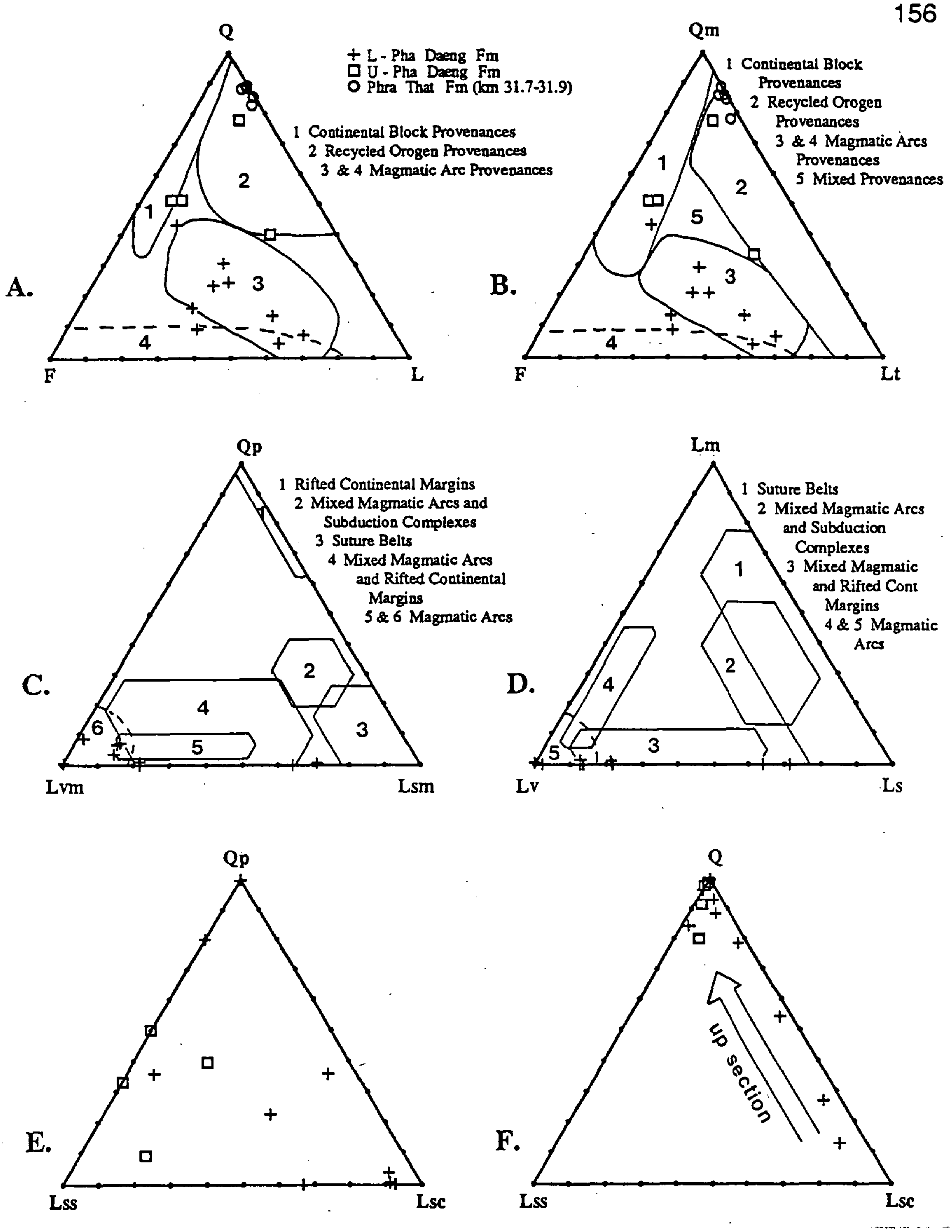


Fig. 6.2. Ternary diagrams of the Phra That and the Pha Daeng sandstones. Provenance fields are from Dickinson, 1985 (QFL & QmFLt), Ingersoll & Suczek, 1979 (QpLvmLsm & LmLvLs) and Dorsey, 1988 (all dashed boundary fields). In general, data of the Phra That fall in recycled orogen provenance; data of lower part of the Pha Daeng Formation fall mainly within magmatic arc provenance. Note the upward decreases in limestone rock fragments (Lsc) of the Pha Daeng Formation.

Table 6.2 Recalculated framework modes including mean and one standard deviation for each group of samples and for the Phra That and Pha Daeng Formations. Samples are arranged regardless of stratigraphic height. See Table 6.1 for explanation of symbols. R-G = Rong Kwang-Ngao highway, L-D = Lampang-Denchai highway. For original point-count data see Appendix A-2

Sample Number	QFL%			QmFLt%			QpLvmLsm%			LmLvLs%			QpLssLsc%			QLssLsc%			Grain size	Qp/Q	P/F	Lv/L	Location
	Q	F	L	Qm	F	Lt	Qp	Lvm	Lsm	Lm	Lv	Ls	Qp	Lss	Lsc	Q	Lss	Lsc					
																							L - Pha Daeng Fm
PL360	23.4	42.7	33.9	21.0	42.7	36.3	6.7	81.5	11.9	.0	87.3	12.7	36.0	56.0	8.0	84.5	13.6	1.9	f	0.10	1.00	0.87	Doi Pha Daeng
PL361	43.1	42.9	14.0	43.1	42.9	14.0	.0	78.2	21.8	.0	78.2	21.8	.0	33.3	66.7	93.4	2.2	4.4	c	0.00	0.95	0.78	Doi Pha Daeng
PL387	13.2	31.7	55.1	13.2	31.7	55.1	.0	35.7	64.3	.0	35.7	64.3	.0	7.1	92.9	27.2	5.2	67.6	m	0.00	1.00	0.36	Doi Pha Daeng
PL388	7.0	26.2	66.8	6.7	26.2	67.1	.4	28.7	71.0	.0	28.8	71.2	.5	8.5	91.0	12.8	7.5	79.7	m	0.03	1.00	0.29	Doi Pha Daeng
PL390	9.1	54.4	36.5	8.8	54.4	36.8	.8	77.9	21.4	.8	78.3	20.9	3.6	7.1	89.3	54.2	3.4	42.4	m	0.03	0.99	0.78	Doi Pha Daeng
PL507	4.5	34.0	61.5	4.2	34.0	61.8	.4	99.2	.4	.4	99.6	.0	100.0	.0	.0	100.0	.0	.0	m	0.06	1.00	1.00	Km 45.2 R-N
PL656	15.9	52.4	31.6	13.5	52.4	34.1	7.1	80.2	12.7	.0	86.3	13.7	36.0	8.0	56.0	78.7	2.7	18.7	f	0.15	0.99	0.86	Huai Nam Lon
PL657	30.5	36.6	32.9	29.3	36.6	34.1	3.5	83.5	12.9	1.2	86.4	12.3	23.1	30.8	46.2	88.2	4.7	7.1	c-m	0.04	0.99	0.86	Huai Lon
PL701	24.3	38.1	37.6	20.8	38.1	41.2	8.6	89.2	2.2	.0	97.6	2.4	80.0	20.0	.0	96.5	3.5	.0	c	0.15	1.00	0.98	Km 61.6 R-N
Mean	19.0	39.9	41.1	17.8	39.9	42.3	3.1	72.7	24.3	.3	75.4	24.4	31.0	19.0	50.0	70.6	4.8	24.6		0.06	0.99	0.75	
SD	12.6	9.3	16.8	12.4	9.3	16.4	3.5	23.9	25.7	.5	25.6	25.7	36.9	18.0	39.0	31.9	3.9	31.0		0.06	0.02	0.26	
																							U - Pha Daeng Fm
PL401	40.2	18.7	41.1	33.5	18.7	47.8	-	-	-	-	-	-	39.6	39.6	20.8	79.9	13.2	6.9	c	0.17	0.90	0.69	Doi Pha Daeng
PL403	78.2	8.3	13.5	77.4	8.3	14.2	-	-	-	-	-	-	9.3	72.1	18.6	91.9	6.5	1.7	vf	0.01	0.96	0.41	Doi Pha Daeng
PL404	51.8	37.2	11.0	51.2	37.2	11.6	-	-	-	-	-	-	33.3	66.7	.0	97.7	2.3	.0	vf	0.01	0.95	0.78	Doi Pha Daeng
PL405	51.8	39.9	8.3	51.2	39.9	8.9	-	-	-	-	-	-	50.0	50.0	.0	98.9	1.1	.0	vf	0.01	0.99	0.86	Doi Pha Daeng
Mean	55.5	26.0	18.5	53.3	26.0	20.6	-	-	-	-	-	-	33.1	57.1	9.8	92.1	5.8	2.1		0.05	0.95	0.68	
SD	16.1	15.1	15.2	18.1	15.1	18.2	-	-	-	-	-	-	17.3	15.0	11.4	8.7	5.5	3.3		0.08	0.04	0.20	
Mean (Total)	30.2	35.6	34.1	28.8	35.6	35.6	-	-	-	-	-	-	31.6	30.7	37.6	77.2	5.1	17.7		0.06	0.98	0.73	
SD(Total)	21.8	12.6	19.1	21.8	12.6	19.3	-	-	-	-	-	-	31.3	24.6	37.6	28.3	4.2	27.6		0.06	0.03	0.23	
																							Phra That Fm
PL602	88.2	2.3	9.6	85.9	2.3	11.8	-	-	-	-	-	-	-	-	-	-	-	-	m	0.03	1.00	0.97	Km 31.7-31.9
PL603	82.6	2.5	14.9	78.2	2.5	19.3	-	-	-	-	-	-	-	-	-	-	-	-	m	0.05	1.00	0.94	Km 31.7-31.9
PL604	88.6	.8	10.6	85.6	.8	13.6	-	-	-	-	-	-	-	-	-	-	-	-	m	0.03	1.00	0.95	Km 31.7-31.9
PL605	85.2	.8	14.0	84.4	.8	14.8	-	-	-	-	-	-	-	-	-	-	-	-	m	0.01	1.00	0.94	Km 31.7-31.9
PL606	89.2	.3	10.5	88.5	.3	11.3	-	-	-	-	-	-	-	-	-	-	-	-	m	0.01	1.00	0.95	Km 31.7-31.9
Mean	86.8	1.3	11.9	84.5	1.3	14.2	-	-	-	-	-	-	-	-	-	-	-	-		0.03	1.00	0.95	
SD	2.8	1.0	2.4	3.8	1.0	3.2	-	-	-	-	-	-	-	-	-	-	-	-		0.02	0.00	0.01	

6.3.2 Petrography and provenance and of the Hong Hoi sandstones

The Hong Hoi sandstones considered here are mainly from the type locality (Huai Mae Dum through Huai Muang) and adjacent areas. The Hong Hoi sandstones are composed mainly of lithic arkose and feldspathic litharenite (Folk, 1974) characterized by predominant plagioclase and volcanic rock fragments, with minor plutonic and quartz fragments and rare sedimentary rock fragments (Figs. 6.1 B-F). Limestone rock fragments are the only significant exception, and commonly feature shallow water characteristics. Hong Hoi sandstones are grain-supported, poorly sorted, fine- to coarse-grained and immature. Quartz generally forms less than 15% of the whole rock and is mainly monocrystalline and angular to subrounded with straight extinction. Some clearly exhibit volcanic features such as clear texture, embayment filled by aphanitic volcanic grains, and bipyramidal crystals (Fig. 6.1 B). Quartz content may be up to 25% where the rock composition consists of a substantial amount of potassium feldspar and/or sedimentary rock fragments. Boehm lamellae, displaying two strain directions, may be observed in some quartz grains (Fig. 6.1 E). Feldspar and lithic fragments constitute about the same proportion, ranging between 20% and 50% of the whole rock. Plagioclase is mainly sodic to intermediate in composition, subhedral to euhedral, occurring either as a single grain or as a phenocryst, and commonly displaying polysynthetic twinning. Oscillatory zoning is rare (Fig. 6.1 F). Potassium feldspar occurs locally (Fig. 6.1 C), particularly in the lower part of the Mae Lu Sandstone Member, and is anhedral to subhedral, light brown in plane-polarized light, commonly showing less alteration than plagioclase (under crossed polars). Perthitic texture is common. Volcanic rock fragments are subangular to rounded, displaying better sphericity than other associated detrital fragments, and feature microlitic, felsitic and lathwork textures with rare vitric textures. Some contain feldspar phenocrysts and a few grains contain quartz phenocrysts. Matrix generally forms less than 10%. Rare heavy minerals include epidote, magnetite, pyroxene, hornblende and zircon.

The sandstone composition of the Hong Hoi Formation is rather consistent. On the QFL and QmFLt diagrams most of them fall in the magmatic arc provenance areas (Figs. 6.3 A,B), and on the QpLvmLsm and LmLvLs diagrams they also plot in magmatic arc provenances with a possibility of deposition in forearc and back arc areas (Figs. 6.3 C,D). According to Dickinson and Suczek (1979), sources for the magmatic arc provenance field are active arc orogens of island arcs or active continental margins. The average ratio of Qp/Q of 0.06, P/F of 0.94 and Lv/L of 0.95 of the Hong Hoi sandstones are similar to the 0.07, 0.83, 0.98 values, respectively, for sandstones derived from magmatic arcs (Table 6.5). Volcanic sources for the Hong Hoi sandstones are also indicated by abundant volcanic rock fragments and plagioclase, and the presence of volcanic quartz and oscillatory zoned plagioclase (MacKenzie et al., 1982; Helmold, 1985). The volcanic source was probably andesite or more felsic in composition, as suggested by abundant microlitic texture in volcanic fragments, high P/F ratio (approaching unity, Table 6.3), and low quartz contents (Dickinson, 1970). Occasionally abundant potassium feldspar suggests the magmatic arcs were partly dissected, and that granitic roots of felsitic volcanoes were being eroded.

Similar sandstone compositions of quartz-poor volcaniclastics are reported from forearc basins ($Q_8F_{60}L_{32}$, $Qm_6F_{60}Lt_{34}$, Dorsey, 1988) and island arc settings (Crook, 1974; Dickinson and Suczek, 1979; Maynard et al., 1982; Valloni and Mezzadri, 1984), and from successor basins (Valloni and Zuffa, 1984). Sediments of the last setting differ from the first two in that they contain substantial amounts of sedimentary and metamorphic rock fragments, similar to sediments occurring in the Basin and Range Province (Hodges, 1989). Scarce sedimentary, except occasional limestone, and metamorphic rock fragments rule out the likelihood of synorogenic sources (Allen et al., 1986; Schwab, 1986) for the Hong Hoi sandstones. The possibility that the source region was a stable cratonic block with generally low relief, low P/F ratio and quartzose composition, can also be ruled out. Hong Hoi sandstones are most similar to forearc sandstones and this interpretation is supported by the rare earth element study (see below). Rare paleocurrents obtained from cross-bedding indicate approximately N-S directional paleoflow possibly parallel to the axis of the depositional basin.

In summary, compositional characteristics, including immature texture, abundant volcanic rock fragments and rare other lithic fragments indicate that the Hong Hoi detritus was derived from nearby volcanic rocks. The Hong Hoi Formation at Huai Mae Dum is currently flanked by the "Permo-Triassic volcanics". However, the current volcanic exposures consist mainly of acid to intermediate volcaniclastics and have not been chemically analyzed.

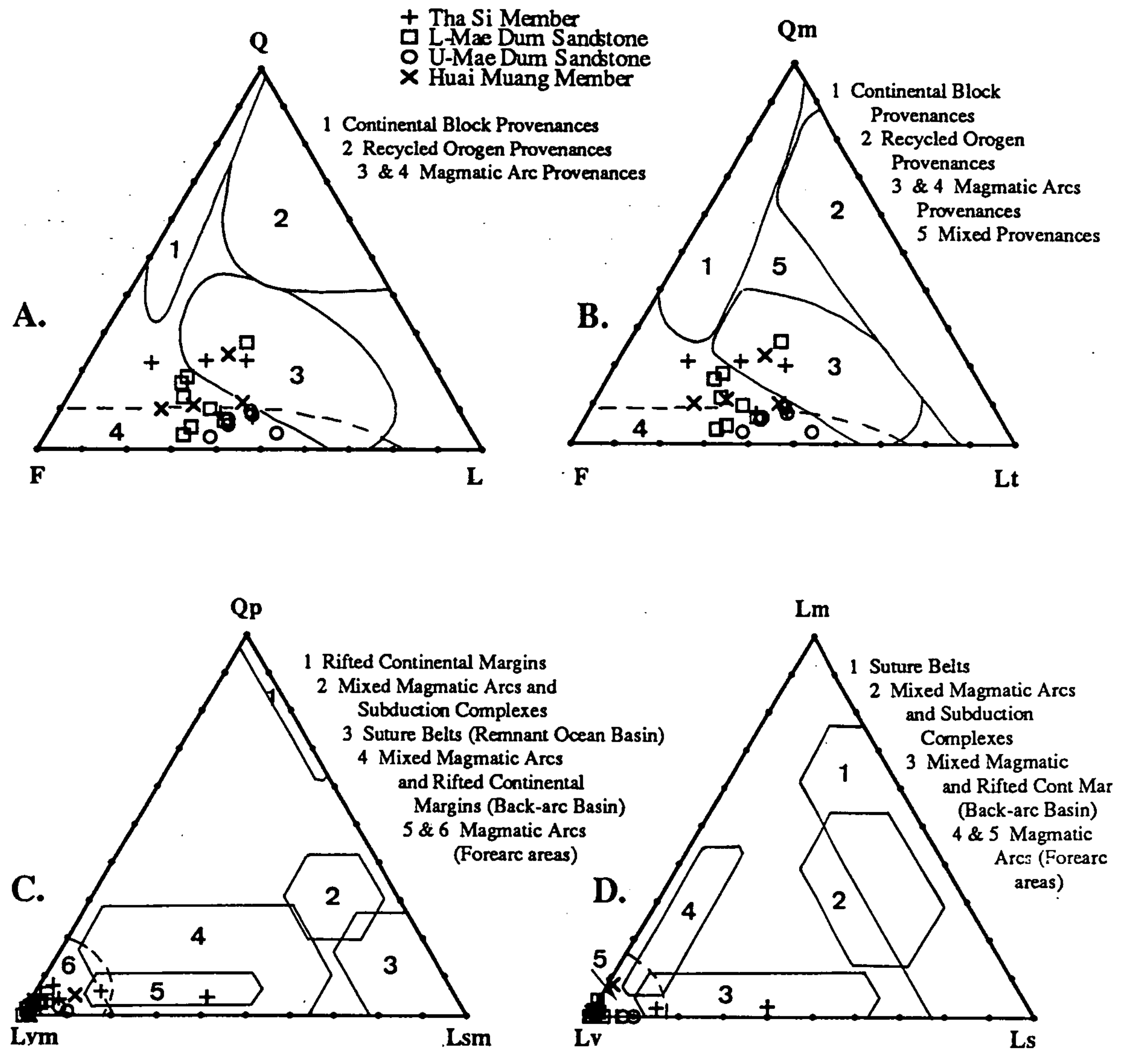


Fig. 6.3 Ternary diagrams of the Hong Hoi sandstones. Provenance fields are from Dickinson (1985) for the QFL & QmFLt, Ingersoll and Suczek (1979) for the QpLvmLsm & LmLvLs, and Dorsey (1988) for all dashed-boundary fields. In general, the data fall in magmatic arc provenances with possibilities of deposition in forearc and back-arc basins.

Table 6.3 Recalculated point-count data from the Hong Hoi Formation, including mean and one standard deviation for each group of samples and for the Hong Hoi Formation as a whole. Samples are arranged without regard to stratigraphic position. See Table 6.1 for explanation of symbols. For original point-count data see Appendix A-1.

Sample Number	QFL%			QmFLt%			QpLvmLsm%			LmLvLs%			Grain Size	Qp/Q	P/F	Lv/L	Location
	Q	F	L	Qm	F	Lt	Qp	Lvm	Lsm	Lm	Lv	Ls					
																	Tha Si Member
PL365	22.6	50.9	26.5	21.5	50.9	27.6	4.3	56.4	39.4	2.2	58.9	38.9	vf	0.05	1.00	0.59	Huai Mae Dum
PL476	22.6	41.8	35.6	20.2	41.8	38.0	6.3	78.9	14.8	1.7	84.2	14.2	c	0.11	0.99	0.84	Ban Pang La
LSM1	9.1	54.6	36.3	7.6	54.6	37.9	4.1	89.7	6.2	.0	93.5	6.5	m	0.17	0.99	0.94	West of Doi Long
LSM2	22.5	63.1	14.4	21.3	63.1	15.6	7.6	89.4	3.0	3.3	96.7	.0	c	0.05	0.78	0.97	West of Doi Long
LSM3	8.3	47.5	44.2	8.0	47.5	44.5	.6	98.8	.6	.0	99.4	.6	c	0.03	0.98	0.99	West of Doi Long
Mean	17.0	51.6	31.4	15.7	51.6	32.7	4.6	82.6	12.8	1.4	86.5	12.0		0.08	0.95	0.87	
SD	7.6	8.0	11.4	7.2	8.0	11.3	2.6	16.3	15.8	1.4	16.5	16.1		0.06	0.10	0.16	
																	L - Mae Dum Sandstone
PL351	13.4	60.5	26.1	11.9	60.5	27.6	5.6	91.6	2.8	.0	97.0	3.0	m	0.12	1.00	0.97	Huai Mae Dum
PL353	18.7	57.0	24.3	18.0	57.0	24.9	2.7	94.6	2.7	.9	97.2	1.8	c	0.04	0.72	0.97	Huai Mae Dum
PL353	17.3	59.3	23.4	16.5	59.3	24.2	3.2	94.7	2.1	1.1	97.8	1.1	c	0.04	0.70	0.98	Huai Mae Dum
PL353-1	27.5	39.5	33.0	26.3	39.5	34.3	3.6	92.7	3.6	3.8	96.2	.0	c	0.05	0.77	0.96	Huai Mae Dum
PL354	5.4	62.6	31.9	4.7	62.6	32.6	2.2	96.4	1.4	1.5	98.5	.0	f	0.13	0.98	0.99	Huai Mae Dum
PL355	7.2	54.7	38.1	6.7	54.7	38.6	1.4	96.4	2.2	.7	97.8	1.5	m-c	0.08	0.95	0.98	Huai Mae Dum
PL626	3.3	65.6	31.1	3.3	65.6	31.1	.0	100.0	.0	.0	100.0	.0	m-f	0.00	0.95	1.00	Huai Mae Dum
SSM1	10.4	56.3	33.3	9.8	56.3	33.8	1.5	98.5	.0	.0	100.0	.0	m-c	0.05	0.96	1.00	West of Doi Long
Mean	12.9	56.9	30.2	12.2	56.9	30.9	2.5	95.6	1.9	1.0	98.1	.9		0.06	0.88	0.98	
SD	8.0	7.9	5.1	7.8	7.9	5.0	1.7	2.8	1.3	1.3	1.4	1.1		0.04	0.13	0.01	
																	U - Mae Dum Sandstone
PL367	8.9	47.5	43.6	7.7	47.5	44.7	2.5	96.2	1.3	.0	98.7	1.3	c	0.13	0.99	0.99	Huai Muang
PL368	3.0	60.0	37.0	2.8	60.0	37.2	.5	98.2	1.4	.0	98.6	1.4	m-f	0.06	0.95	0.99	Huai Muang
PL370	7.7	53.3	39.0	6.7	53.3	40.0	2.4	97.6	.0	.0	100.0	.0	m	0.13	1.00	1.00	Huai Muang
PL371	6.2	54.0	39.7	6.2	54.0	39.7	.0	98.7	1.3	.0	98.7	1.3	m	0.00	0.99	0.99	Huai Muang
PL372	9.6	47.3	43.1	9.3	47.3	43.4	.7	89.6	9.7	.0	90.2	9.8	c	0.03	1.00	0.90	Huai Muang
SSM5	3.9	44.4	51.7	3.1	44.4	52.5	1.6	91.0	7.4	.0	92.5	7.5	m-f	0.21	0.99	0.92	West of Doi Long
Mean	6.5	51.1	42.3	6.0	51.1	42.9	1.3	95.2	3.5	.0	96.5	3.5		0.09	0.99	0.96	
SD	2.7	5.7	5.2	2.6	5.7	5.4	1.1	3.9	4.0	.0	4.1	4.1		0.08	0.02	0.04	
																	Huai Muang Member
PL357	10.1	67.4	22.6	10.1	67.4	22.6	.0	98.7	1.3	.0	98.7	1.3	m	0.00	1.00	0.99	Huai Muang
PL374	11.9	48.2	39.9	10.4	48.2	41.4	3.6	95.7	.7	.7	99.3	.0	m	0.13	0.99	0.99	Huai Muang
PL377	24.3	45.2	30.5	22.6	45.2	32.2	5.2	85.7	9.1	8.2	90.4	1.4	c	0.07	1.00	0.90	Huai Muang
USM1	11.2	59.2	29.6	11.2	59.2	29.6	.0	98.1	1.9	.9	98.1	.9	c	0.00	1.00	0.98	West of Doi Long
Mean	14.4	55.0	30.6	13.6	55.0	31.4	2.2	94.5	3.3	2.5	96.6	.9		0.05	1.00	0.97	
SD	6.6	10.2	7.1	6.0	10.2	7.8	2.6	6.0	3.9	3.8	4.2	.6		0.06	0.00	0.04	
Mean (Total)	12.4	53.9	33.7	11.6	53.9	34.5	2.6	92.5	4.9	1.1	94.9	4.0		0.07	0.94	0.95	
SD (Total)	7.3	7.7	8.5	7.0	7.7	8.5	2.2	9.4	8.4	1.9	8.8	8.4		0.06	0.10	0.09	

6.3.3 Petrography and provenance of the Pha Daeng sandstones

At the type locality Doi Pha Daeng, the Pha Daeng sandstones range in composition from lithic arkose to feldspathic litharenite (Folk, 1974). In the lower part of the formation, quartz constitutes less than 15% of the whole rock (Fig. 6.4 A) and increases up to 60% in the upper part (Figs. 6.4 B, C). Grain size, in general, decreases upwards. Quartz is mainly monocrystalline, angular to subrounded and, in the lower part of the formation, commonly features embayment and straight extinction. Undulose extinction and polycrystalline quartz (in the sense of Folk, 1974) are common in the upper part of the formation. Boehm lamellae, showing one strain direction, may be observed in some quartz grains. Plagioclase, as in the Hong Hoi Formation, is the major type of feldspar; it is subhedral and acid to intermediate in composition, commonly exhibiting albite twins and generally ranging in proportion between 15% and 40% (Figs. 6.4 A, B). Lithic fragments consist mainly of volcanics and limestones. The latter, based on their lithology, are probably derived from limestone of the underlying Doi Long Formation, and are regarded as extrabasinal grains (Zuffa, 1985). The limestone and volcanic fragments decrease upward. In the upper part, where grain size is finer, sandstones consist mainly of quartz and plagioclase (Table 6.2) with common nonschistose detrital mica.

Sedimentological evidence suggests that the Pha Daeng red beds were formed by gravity flows in fan-delta depositional environments (see CH-5). Deposition in such environments implies significant topographic relief. The sudden occurrence of conglomerates suggests the topographic relief was possibly associated with seismic activity. On QFL, QmFLt, QpLvmLsm and LmLvLs diagrams (Figs. 6.2 A-D), detrital grains in sandstones from the lower part of the Pha Daeng Formation plot mainly in the magmatic arc field and a few in the continental field. This suggests an active magmatic arc which played a major role in supplying the sediments. Rare metamorphic and sedimentary fragments (except limestone) suggest that the topographic relief might have been created by extensional normal fault rather than by compressional fault. Sandstones from the upper part of the formation are quartzose in composition and show variable provenances on QFL and QmFLt plots. They contain less than 10% lithic fragments, and thus are not valid for the QpLvmLsm and LmLvLs plots. As mentioned elsewhere (Dickinson, 1988), the origin of quartzose rocks is often doubtful due to the multicycle origin of quartz. Rare potassium feldspar in the rocks suggests insignificant influence from stable craton sources. Figures 6.2 E and F clearly demonstrate an upwardly decreasing trend of aphanitic limestone fragments.

Fig. 6.4 Photomicrographs of sand grains from the Pha Daeng and Wang Chin Formations.

A) Feldspathic litharenite from lower part of Pha Daeng Formation at Doi Pha Daeng displays abundant limestone fragments (gray), plagioclase (red), quartz (white) and volcanic fragments (Lv); PL, stained thin section. Bar scale is 400 microns. Field sample no PL387 (details see Fig. 2.8 A).

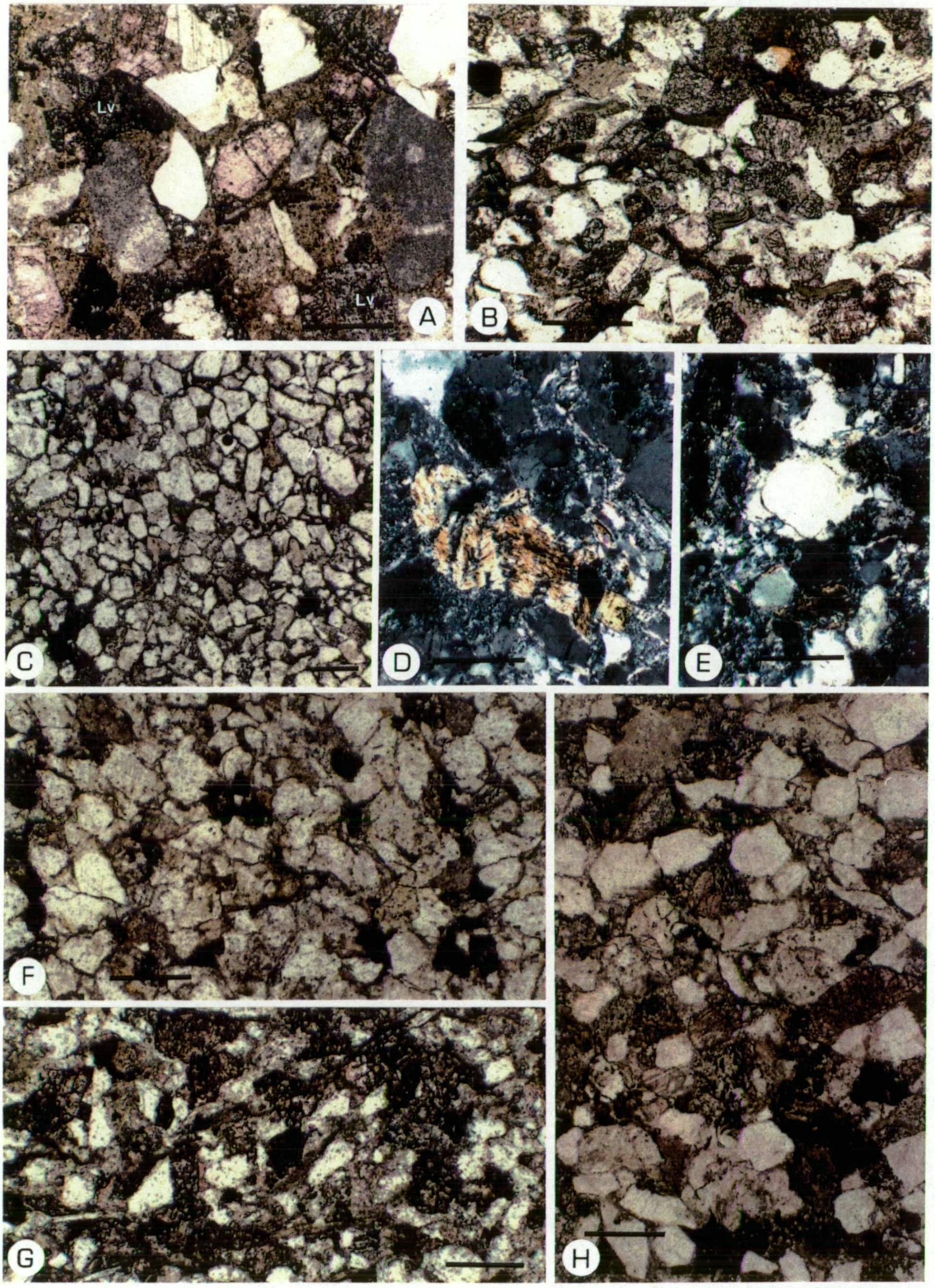
B) Fine-grained lithic arkose from the upper part of the Pha Daeng Formation, at Doi Pha Daeng, with abundant quartz (white), plagioclase (red) and mica (green); PL, stained thin section. Bar scale is 200 microns. Field sample no PL404 (details see Fig. 2.8A).

C) Fine-grained lithic arkose from the upper part of the Pha Daeng Formation with predominant quartz and minor plagioclase; PL, stained thin section. Bar scale is 200 microns. Field sample no PL 403 (details see Fig. 2.8 A).

D) Schistose mica, a metamorphic aphanitic rock gragment (Lm) from the Mae Lu Sandstone Member of Wang Chin Formation at km 55.1-55.9 on the Lampang-Denchai highway; XP. Bar scale is 200 microns. Field sample no PL433 (details see Fig. 2.12 B).

E) Detrital quartz overgrowths in lithic arkose, an indicator of a sedimentary source; same location as Fig. 6.4 D; XP. Bar scale is 200 microns.

F, G & H) Typical views of lithic arkose from Mae Lu Sandstone Member of Wang Chin Formation at km 55.1-55.9, 66.4-66.7 and 68-68.3 on the Lampang-Denchai highway, respectively; PL, stained thin sections. All bar scale are 300 microns. Field sample no PL 436, PL 441 and PL 464, respectively (see fig. 2.12).


Lv
Lv
A
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This evidence, in conjunction with limestone lithology, indicates an exposure to erosion of the underlying Doi Long limestones and also reflects progressive changes of source lithology.

6.3.4 Petrography and provenance of the Wang Chin sandstones

The Wang Chin sandstones considered here came from three sections along the Lampang-Denchai highway at km 55.1-55.9, 66.4-66.7 and 68-68.3, and according to fossils they are middle Carnian, upper Carnian and lower Norian, respectively (see section 2.11). Petrographically, they range in composition from lithic arkose to feldspathic litharenite (Folk, 1974) consisting mainly of quartz, plagioclase and volcanic rock fragments with minor metamorphic and sedimentary rock fragments (Figs. 6.4 D-H). They are grain-supported, moderately to poorly sorted, immature and mostly fine- to medium-grained. They are distinguished from the Hong Hoi sandstones by their higher quartz contents, better roundness in quartz and lesser microlitic texture in volcanic fragments. Quartz ranges in composition between 30 and 50% of the whole rock and is mainly subangular to rounded, having moderate sphericity and undulose extinction. Quartz contents are higher in section km 55.1-55.9 than the other two sections where angular and straight extinction quartz is common. Polycrystalline quartz (Folk, 1974) is common but polycrystalline aphanitic quartz (Qp) is rare. Schistose mica (Fig. 6.4 D) and quartz overgrowths (Fig. 6.4 E) are common and are significant in section km 55.1-55.9. Plagioclase is sodic to intermediate in composition, anhedral to subhedral, subrounded, and of moderate sphericity. It displays approximately equal proportions of twinned and untwinned grains. Volcanic rock fragments display mainly felsitic texture with subordinate microlitic and lathwork textures, and have moderate to high roundness and sphericity. Plagioclase and volcanic fragment contents range between 10% and 35% and are higher in the sections km 66.4-66.7 and 68-68.3 than km 55.1-55.9 (Table 6.4). Rare heavy minerals are epidote, magnetite, hematite and hornblende.

Although detrital modes of Wang Chin sandstones from the three sections (km 55.1-55.9, 66.4-66.7 and 68-68.3) along the Lampang-Denchai highway fall in different provenance fields, they all exhibit magmatic provenance (Fig. 6.5). Their grain ratios (Qp/Q, P/F, Lv/L) are also similar to the values of magmatic arc sands (Table 6.5). During the middle Carnian, sediments (km 55.1-55.9) were mainly derived from recycled orogen sources, possibly uplifted volcanic and sedimentary terranes (Fig. 6.5). This interpretation is supported by the presence of reworked quartz overgrowths and schistose mica and the similarity of grain ratios to those of magmatic arc sands (Table 6.5). The middle Carnian tectonic event probably occurred contemporaneously with uplift of the Doi Long limestone and deposition of the Pha

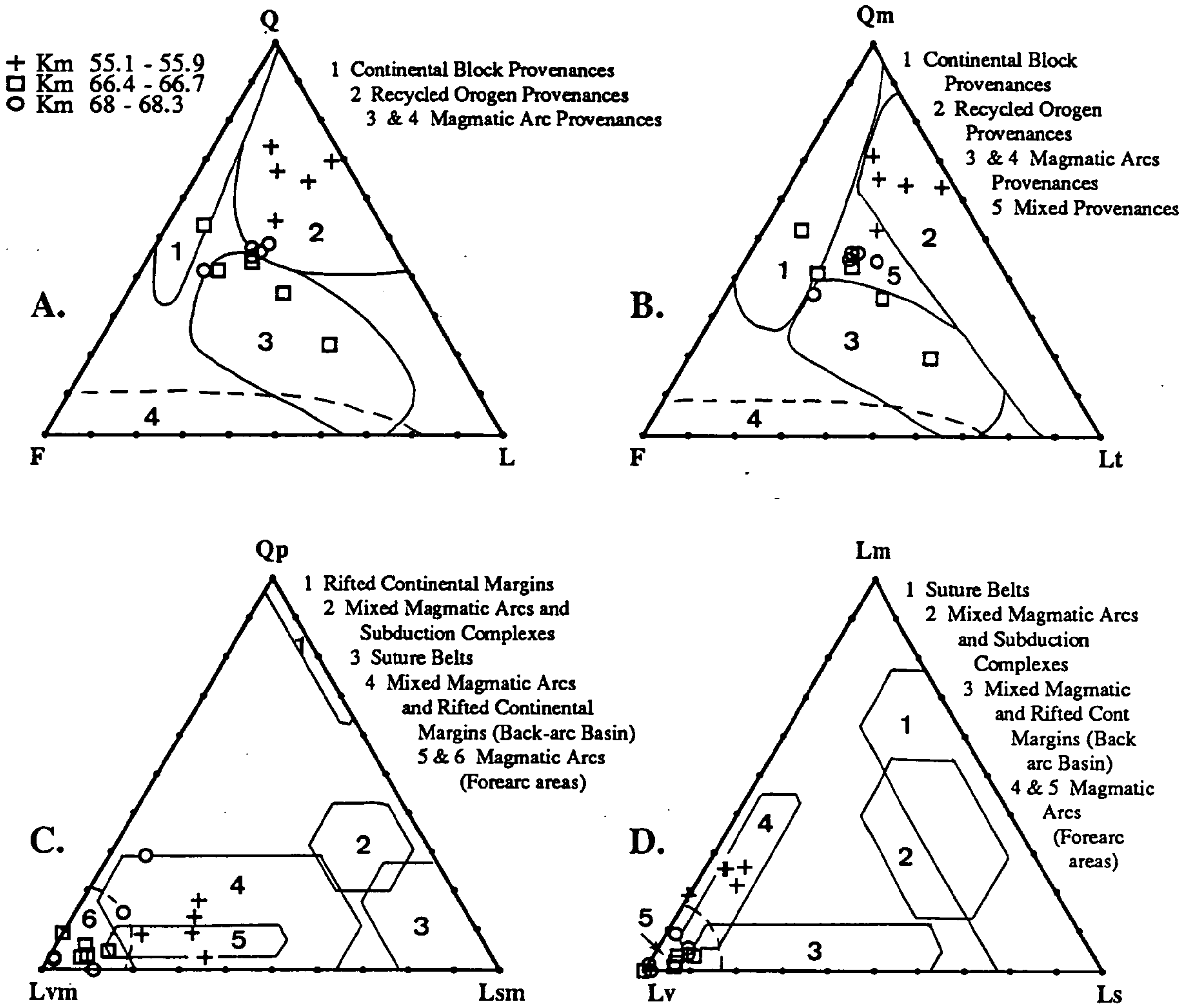


Fig. 6.5 Detrital modes of Wang Chin sandstones plotted on various discriminating ternary diagrams (QFL & QmFLt from Dickinson, 1985; QpLvmLsm & LmLvLs from Ingersoll & Suczek, 1979; all dashed-boundary fields from Dorsey (1988). In general, data fall in three separated areas, recycled orogen for samples from km 55.1-55.9, magmatic arc and mixed provenances for km 66.4 - 66.7 and mixed provenances for km 68 - 68.3. All data fall in forearc and backarc areas. Fossil data indicate that the rocks from km 55.1 - 55.9 are the oldest and km 68 - 68.3 are the youngest.

Table 6.4 Recalculated modal point-count data for the Wang Chin Formation. Mean and one standard deviation for each group of rock samples and for the formation are also provided. Sample numbers are not arranged stratigraphically. See Table 6.1 for explanation of symbols. For original point count data see Appendix A-3

Sample Number	QFL%			QmFLt%			QpLvmLsm%			LmLvLs%			Grain Size	Qp/Q	P/F	Lv/L	Location
	Q	F	L	Qm	F	Lt	Qp	Lvm	Lsm	Lm	Lv	Ls					
PL429	64.4	10.6	25.0	63.6	10.6	25.7	3.0	63.2	33.8	26.4	65.1	8.5	f	0.01	0.98	0.65	
PL433	73.1	14.5	12.4	71.2	14.5	14.2	13.2	60.4	26.4	26.1	69.6	4.3	f	0.03	0.98	0.70	Km 55.1 - 55.9 on the
PL434	66.9	16.1	16.9	65.3	16.1	18.5	8.7	73.9	17.4	19.0	81.0	.0	f	0.02	1.00	0.81	Lampang - Denchai
PL436	54.3	22.9	22.9	52.0	22.9	25.1	9.0	63.0	28.0	22.0	69.2	8.8	f	0.04	0.97	0.69	highway
PL670	69.3	2.8	27.8	63.3	2.8	33.9	17.8	57.0	25.2	26.1	69.3	4.5	c	0.09	1.00	0.69	
Mean	65.6	13.4	21.0	63.1	13.4	23.5	10.3	63.5	26.2	23.9	70.8	5.2		0.04	0.99	0.71	
SD	7.1	7.4	6.3	7.0	7.4	7.5	5.5	6.3	5.9	3.3	5.9	3.6		0.03	0.02	0.06	
PL441	53.2	39.0	7.8	52.5	39.0	8.5	9.1	90.9	.0	.0	100.0	.0	vf	0.01	1.00	1.00	
PL442	22.8	27.0	50.2	19.7	27.0	53.3	5.8	87.7	6.5	.7	93.1	6.2	c	0.14	1.00	0.93	Km 66.4 - 66.7 on the
PL444	43.6	33.0	23.4	42.8	33.0	24.2	3.4	88.1	8.5	3.5	91.2	5.3	m	0.02	0.99	0.91	Lampang - Denchai
PL452	36.2	30.3	33.5	35.1	30.3	34.6	3.1	89.6	7.3	1.6	92.5	5.9	m	0.03	1.00	0.93	highway
PL674	42.0	41.4	16.6	41.2	41.4	17.4	4.5	83.3	12.1	3.2	87.3	9.5	f	0.02	1.00	0.87	
Mean	39.6	34.1	26.3	38.3	34.1	27.6	5.2	87.9	6.9	1.8	92.8	5.4		0.04	1.00	0.93	
SD	11.2	6.0	16.3	12.1	6.0	17.2	2.4	2.9	4.4	1.5	4.6	3.4		0.05	0.01	0.05	
PL464	48.6	26.8	24.5	44.5	26.8	28.6	14.4	75.1	10.5	5.6	87.7	6.7	m	0.08	0.99	0.88	
PL594	46.3	29.9	23.9	46.3	29.9	23.9	.0	88.8	11.3	3.8	88.8	7.5	f	0.00	1.00	0.89	Km 68 - 68.3 on the
PL597	41.5	44.7	13.8	35.8	44.7	19.5	29.0	62.9	8.1	9.1	88.6	2.3	f	0.14	0.99	0.89	Lampang - Denchai
PL597-1	45.3	32.4	22.2	44.7	32.4	22.8	2.6	96.1	1.3	.0	98.6	1.4	f-m	0.01	1.00	0.99	highway
PL598	47.3	31.3	21.4	46.7	31.3	22.0	2.7	95.9	1.4	1.4	98.6	.0	m-f	0.01	0.99	0.99	
Mean	45.8	33.0	21.2	43.6	33.0	23.4	9.8	83.7	6.5	4.0	92.5	3.6		0.05	1.00	0.92	
SD	2.7	6.8	4.3	4.4	6.8	3.4	12.1	14.4	4.9	3.6	5.6	3.3		0.06	0.00	0.06	
Mean (Total)	50.3	26.9	22.8	48.3	26.9	24.8	8.4	78.4	13.2	9.9	85.4	4.7		0.04	0.99	0.85	
SD(Total)	13.6	11.7	10.0	13.5	11.7	10.4	7.6	14.0	10.6	10.7	11.8	3.3		0.05	0.01	0.12	

Table 6.5 Comparison of means and standard deviations of framework grains between the Lampang sandstones and the discriminating values (the values for QpLvmLsm & LmLvLs from Ingersoll and Suczek,1979; and values for QFL , QmFLt and P/F ratios were calculated from Dickinson and Suczek,1979, and for Qp/Q and Lv/L ratios from Dickinson, 1985;
* from Dickinson and Valloni, 1980). Number of data sets shown in parentheses.

Provenances Dickinson&Suczek,1979	QFL%			QmFLt%			Grain Ratio			QpLvmLsm%			LmLvLs%			Provenances Ingersoll &Suczek, 1979
	Q	F	L	Qm	F	Lt	Qp/Q	P/F	Lv/L	Qp	Lvm	Lsm	Lm	Lv	Ls	
Continental Block (1700)	75.1±20.2	21.8±17.9	3.0±2.9	70.4±21.3	21.8±17.9	7.8±6.7	0.07* (155)	0.25* (155)	-	80.4±18.4 (31)	1.0±2.1 (31)	18.7±18.6 (31)	30.7±32.1 (29)	7.0±14.1 (29)	62.3±31.6 (29)	Rifted Continental Margins
Recycled Orogen (1955)	65.2±18.3	9.7±8.0	25.1±16.3	48.3±24.4	9.7±8.0	42.0±24.1	-	0.72	-							
Collision Orogen (639)	71.0±11.4	12.3±8.4	16.7±8.4	62.4±10.9	12.3±8.4	25.2±12.1	0.03	0.66	0.08	13±13.6	8.7±12.9	78.4±16.1	37.9±38.7	9.5±13.1	52.6±37.5	Suture Belts (117)
Foreland Uplifted (1136)	59.2±24.5	8.1±6.5	24.5±15.4	44.1±24.6	8.1±6.5	39.3±22.9	0.30	0.49	0.80	13.7±14.7	52.3±27.3	34.0±31.0	2.6±8.9	62.6±30.8	34.8±28.3	Mixed Magmatic Arcs and rifted Continental margins (56)
Subduction Complex (180)	45.0±15.5	13.5±8.1	41.5±17.3	7.5±3.3	13.5±8.1	79.0±6.1	0.35	0.94	0.33	30.8±11.2	14.4±11.5	55.0±12.0	33.4±20.3	20.1±14.8	46.5±19.4	Mixed Magmatic Arcs and Subduction Complexes (62)
Magmatic Arc (1667)	22.6±12.6	32.3±8.6	45.0±17.0	20.0±12.2	32.3±8.6	47.7±16.7	0.07	0.83	0.98	6.4±4.1	63.3±20.5	30.4±19.8	25.2±19.5	67.6±22.7	7.3±4.9	Magmatic Arcs (199)
Undissected Arc (181)	5.5±4.0	28.6±8.5	65.9±5.9	4.6±3.9	28.6±8.5	66.8±5.5	-	0.97	-							
Transitional Arc (224)	18.7±2.6	28.2±7.0	53.0±6.8	14.7±4.5	28.2±7.0	57.1±6.9	-	0.85	-							
Dissected Arc (1262)	33.4±6.3	36.5±7.9	30.1±8.2	30.7±5.7	36.5±7.9	32.8±8.5	-	0.71	-							
Phra That Formation (5)	86.8±2.8	1.3±1.0	11.9±2.4	84.5±3.8	1.3±1.0	14.2±3.2	0.03±0.02	1.00	0.95±0.01							Mixed recycled orogen and ?continental block
Hong Hoi Formation (23)	12.4±7.3	53.9±7.7	33.7±8.5	11.6±7.0	53.9±7.7	34.5±8.5	0.07±0.06	0.94±0.10	0.95±0.09	2.6±2.2	92.5±9.4	4.9±8.4	1.1±1.9	94.9±8.8	4.0±8.4	Magmatic arcs
lower part of Pha Daeng Formation (9)	19.0±12.6	39.9±9.3	41.1±16.8	17.8±12.4	39.9±9.3	42.3±16.4	0.06±0.06	0.99±0.02	0.75±0.26	3.1±3.5	72.7±23.9	24.3±25.7	0.3±0.5	75.4±25.6	24.4±25.7	Magmatic arcs
Wang Chin Formation (15)	50.3±13.6	26.9±11.7	22.8±10.0	48.3±13.5	26.9±11.7	24.8±10.4	0.04±0.05	0.99±0.01	0.85±0.12	8.4±7.6	78.4±14.0	13.2±10.6	9.9±10.7	85.4±11.8	4.7±3.3	Mixed magmatic arc and recycled orogen
Km 55.1-55.9 (5)	65.6±7.1	13.4±7.4	21.0±6.3	63.1±7.0	13.4±7.4	23.5±7.5	0.04±0.03	0.99±0.02	0.71±0.06	10.3±5.5	63.5±6.3	26.2±5.9	23.9±3.3	70.8±5.9	5.2±3.6	Recycled orogen plus magmatic arcs
Km 66.4-66.7 (5)	39.6±11.2	34.1±6.0	26.3±16.3	38.3±12.1	34.1±6.0	27.6±17.2	0.04±0.05	1.00±0.01	0.93±0.05	5.2±2.4	87.9±2.9	6.9±4.4	1.8±1.5	92.8±4.6	5.4±3.4	Mixed magmatic arc and recycled orogen
Km 68-68.3 (5)	45.8±2.7	33.0±6.8	21.2±4.3	43.6±4.4	33.0±6.8	23.4±3.4	0.05±0.06	1.00	0.92±0.06	9.8±12.1	83.7±14.4	6.5±4.9	4.0±3.6	92.5±5.6	3.6±3.3	Mixed magmatic arc and recycled orogen

Daeng Formation, to the present west. The tectonic activity was probably mild and discontinuous as suggested by the rare sedimentary and metamorphic fragments, continuation of volcanism, and lack of coarsening upward sequences in the Pha Daeng Formation. During the late Carnian (km 66.4-66.7), source rocks were dominated by magmatic arcs (Figs. 6.5 A, B). However, roundness in the undulose quartz grains reflect significant transport, possibly from sedimentary sources. Paucity of twinned plagioclase may have been caused by transportation process and decreasing in frequency as size decreases (Helmold, 1985). Sources of the lower Norian sediments (km 68-68.3) were a magmatic arc and possibly a recycled orogen (Fig. 6.5). The volcanic source is clearly indicated by abundant volcanic rock fragments and plagioclase (Fig. 6.4 H). Volcanic rock fragments of the Wang Chin sandstones show mainly felsitic texture, suggesting the original source rocks were dacite and rhyolite (Dickinson, 1970). The lack of potassium feldspar in the Wang Chin sandstones implies that plutonic roots of the arc terrane were not exposed at that time. Changes in source rock compositions from andesite in the Hong Hoi sandstones to dacite and rhyolite in Wang Chin sandstones possibly imply comagmatic sources, since composition of arc volcanism commonly changes from basic to felsic through time.

6.4 Sandstone provenance as evidenced by rare earth elements

Rare earth element (REE) contents of detrital sediments show insignificant changes during sedimentary processes such as transportation, deposition and diagenesis except under intensive weathering conditions where there is slight enrichment of light REE (Bhatia, 1985; Bhatia and Crook, 1986; McLennan, 1989). Rare earth abundances in sediments, particularly those deposited close to active tectonic settings where the weathering conditions are generally low, reflect the source composition. Thus, their REE abundances have been used to discriminate the tectonic settings of depositional basins (Bhatia, 1985; Floyd and Leveridge, 1987).

Twenty samples, all turbiditic sandstones, subdivided into eight from the Hong Hoi Formation and the remainder from the Wang Chin Formation, were analyzed for the REE (Fig. 6.6, Table 6.6) by XRF spectrometry (Robinson et al., 1986). REE chondrite-normalized factors are from Taylor and Gorton (1977). REE abundances in sediments may be controlled by size fraction. Sand fraction tends to have lower REE abundances and La/Yb ratio than silt and mud fractions due to REE being extremely low in quartz.

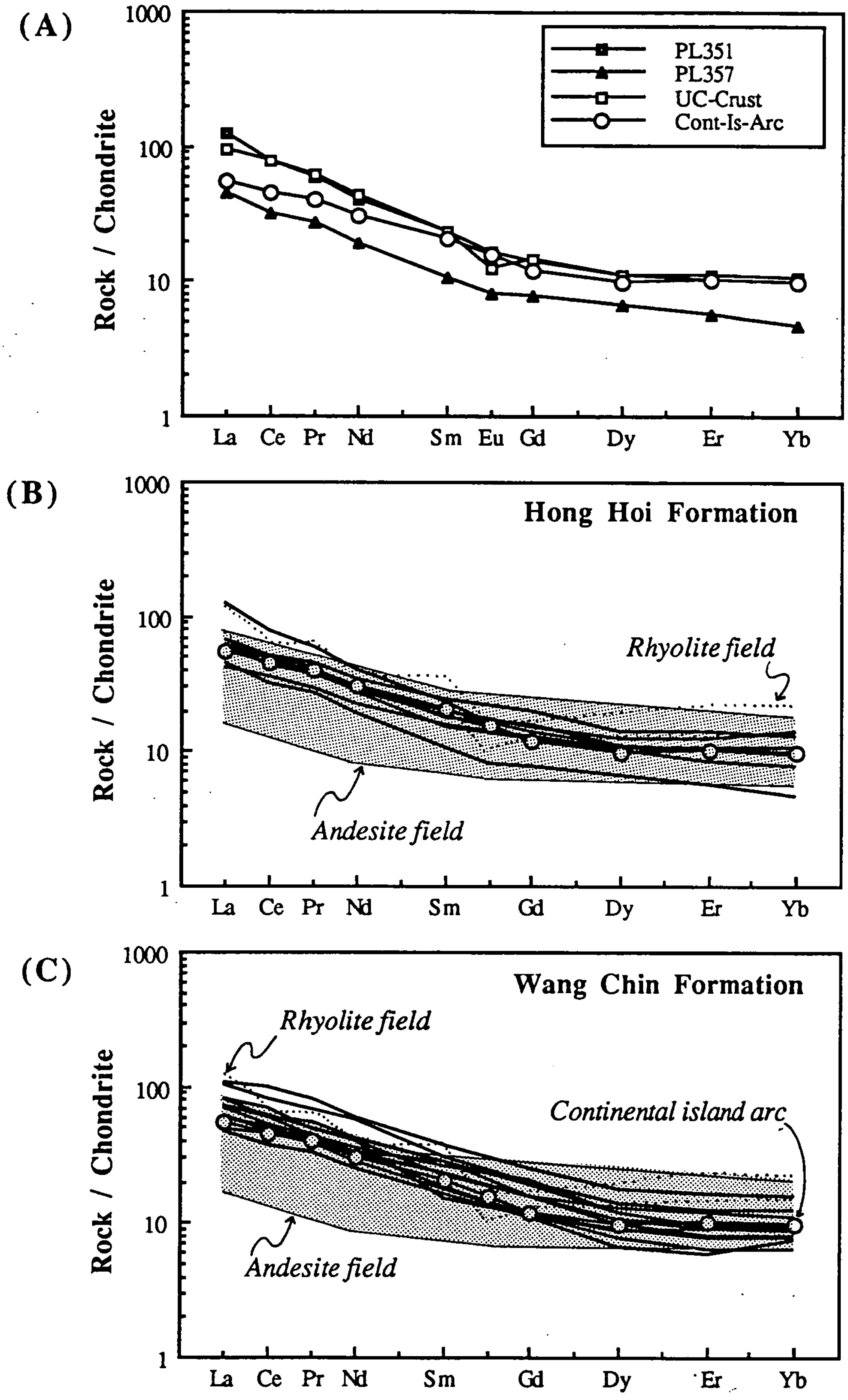


Fig. 6.6 Chondrite-normalized REE plots for the Hong Hoi and Wang Chin sandstones; **A**) compared with the patterns of the upper continental crust (McLennan, 1989) and continental island arc (Bhatia, 1985), **B** & **C**) REE patterns of the Hong Hoi and Wang Chin sandstones, respectively, showing continental island arc (circle), andesite (Cole et al., 1983) and rhyolite fields (Taylor et al., 1968).

Table 6.6 Rare earth abundances of the Hong Hoi and Wang Chin sandstones (in ppm).

	Hong Hoi Formation								Wang Chin Formation												Hong Hoi#	Wang Chin#
	PL365	PL351	PL354	PL371	PL356	PL375	PL357	PL477	PL419	PL420	PL422-1	PL429	PL433	PL434	PL436	PL439	PL441	PL445	PL448	PL464		
Comp.	SS(m)	SS(m)	SS(f)	SS(m)	SS(vf)	SS(vf)	SS(m)	SS	SS(vf)	SS(vf)	SS(m-f)	SS(f)	SS(vf)	SS(f)	SS(f)	SS	SS(vf)	SS	SS	SS(m)		
La	18.50	38.90	18.10	13.00	20.70	19.60	14.40	18.70	25.90	32.00	22.80	25.10	22.40	14.80	21.80	34.00	18.70	18.40	19.10	15.50	20.24	22.54
Ce	35.00	63.70	39.20	28.50	41.00	40.10	26.20	41.70	47.70	66.40	49.80	55.30	48.30	30.40	42.10	80.90	41.00	39.60	37.90	36.60	39.43	48.00
Pr	4.33	6.94	NA	3.40	4.86	4.43	3.09	5.31	NA	NA	NA	5.55	6.27	3.88	5.11	9.47	5.13	4.76	4.90	4.38	4.05	4.12
Nd	18.40	24.00	16.60	13.10	16.00	16.90	11.30	20.60	20.00	33.60	23.60	23.90	24.40	14.70	21.60	35.40	19.10	19.60	20.00	17.00	17.11	22.74
Sm	3.36	4.37	3.81	2.95	2.90	3.50	2.01	4.59	3.50	5.76	4.30	2.86	5.38	3.13	5.07	7.02	4.35	4.48	5.32	3.37	3.44	4.54
Eu	NA	1.18	NA	NA	NA	NA	0.57	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Gd	4.00	3.62	3.83	3.34	3.16	3.25	2.00	5.08	2.91	5.18	4.00	2.94	3.97	2.86	5.29	6.41	4.12	4.11	4.85	3.00	3.54	4.14
Dy	3.61	3.59	3.95	3.47	3.41	3.26	2.10	4.58	2.88	4.55	4.09	2.87	3.19	2.13	3.86	5.67	3.43	3.41	3.82	2.50	3.50	3.53
Er	2.12	2.15	2.65	2.21	2.12	1.78	1.21	2.90	1.64	2.63	2.49	1.92	1.71	1.27	2.03	3.50	2.10	1.92	2.01	1.36	2.14	2.05
Yb	2.02	2.00	2.83	2.19	1.92	1.59	0.97	2.62	1.60	2.55	2.28	1.94	1.67	1.53	1.94	3.28	1.92	1.82	1.89	1.30	2.02	1.98
ΣREE	91.34	150.45	90.97	72.16	96.07	94.41	63.85	106.08	106.13	152.67	113.36	122.38	117.29	74.70	108.80	185.65	99.85	98.10	99.79	85.01	95.45	113.64
Eu/ Eu*	NA	0.89	NA	NA	NA	NA	0.87	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ΣLREE / ΣHREE	6.77	12.14	5.86	5.44	8.05	8.56	9.08	5.99	10.75	9.24	7.81	11.66	10.13	8.59	7.29	8.84	7.63	7.71	6.94	9.42	7.53	8.83
La / Yb	9.16	19.45	6.40	5.94	10.78	12.33	14.85	7.14	16.19	12.55	10.00	12.94	13.41	9.67	11.24	10.37	9.74	10.11	10.11	11.92	10.03	11.52
La_N/Yb_N	6.05	12.84	4.22	3.92	7.12	8.14	9.80	4.71	10.69	8.29	6.60	8.54	8.86	6.39	7.42	6.84	6.43	6.68	6.67	7.87	6.62	7.61
Y	25.00	22.00	28.00	22.00	22.00	21.00	15.00	28.00	18.00	25.00	28.00	18.00	18.00	12.00	23.00	33.00	20.00	20.00	19.00	15.00	22.88	20.75

Note: $Eu/Eu^* = EuN/(SmN*GdN)^{0.5}$, where "N" denotes chondrite-normalized values (McLennan, 1989); LREE = La-Sm while HREE = Gd-Yb; SS stands for sandstone, m = medium grain, f = fine, vf = very fine; NA = not avialable; # mean element abundance.

In general, light rare earth elements (LREE) and La/Yb ratio systematically increase from oceanic island arc setting to continental island arc (thin active continental margin) to thick active continental margin to passive margin settings (Bhatia and Crook, 1986). Sediments of continental island arcs and thin active continental margins (New Zealand type) are distinguished from sediments of thick active continental margin (Andean type), passive margins and cratonic basins by their lower ΣREE abundance, lower La/Yb ratio and the small negative Eu anomaly on rock/chondrite plots (Bhatia, 1985). Rare-earth patterns of the last three settings are also similar to the secular trends of the upper continental crust, Post-Archean Average Australian Shale (PAAS), North America Shale Composite (NASC), and European Shale (ES) that all have a pronounced negative Eu anomaly on rock/chondrite plots (Fig. 6.6 A, and also Bhatia, 1985; McLennan, 1989).

REE patterns of the Hong Hoi sandstones and the Wang Chin sandstones are similar. They clearly differ from sediments of the oceanic island arcs due to the latter typically having LREE depletion on rock/chondrite plots and low La_N/Yb_N ratios (Table 6.7). The Hong Hoi and Wang Chin sandstones have the contents of La, Ce, ΣREE and the ratio of La/Yb, La_N/Yb_N and ΣLREE/ΣHREE, which appear to be typical of sands in sedimentary basins (Bhatia, 1985), adjacent to the continental island arcs and arcs formed on thin active continental margins rather than to sediments in oceanic island arcs, thick continental margins and passive margins (Table 6.7). This suggests that the sandstone detritus may have been derived from a continental island arc or arc formed on thin continental margins. Supporting this are the small negative Eu anomalies on rock/chondrite plots of sample PL351 and PL357 (Fig. 6.6 A) which are similar to those shown in REE patterns of continental island arc sediments. Unfortunately, Eu could only be determined in two samples in the present study.

The interpretation of thin continental margin is supported by the fact that the oldest dated rocks in central north Thailand are Permian, and many formerly inferred as Carboniferous or Silurian-Devonian rocks are now remapped as Permian or younger (Chaodumrong and Jeumton, 1985; Wolfart, 1987; Charoenpravat et al., 1987). Absolute REE abundances and normalized patterns suggest source volcanics of andesite to felsic composition (Cole et al., 1983; Taylor et al., 1968; Figs. 6.6 B, C). Magmatically, rhyolite and dacite or silica rich magma are volumetrically abundant in active continental margin settings rather than continental island arc settings, while the occurrence of andesite is the reverse (Wilson, 1989). The higher LREE enrichment in the Wang Chin sandstones compared to the Hong Hoi sandstones is possibly both a source effect, and also due to the finer grain size of the former. This interpretation is consistent with a study on the detrital modes in sandstone compositions (details see 6.3).

Table 6.7 Comparison of mean REE characteristics of Hong Hoi and Wang Chin sandstones to the values (in ppm) of turbiditic sandstones from various tectonic settings (Discriminatory data from Bhatia, 1985)

Tectonic settings	Provenances	La	Ce	ΣREE	La/Yb	La_N/Yb_N	ΣLREE/ ΣHREE	Eu/Eu*
Ocean island arcs	Undissected magmatic arcs	8±1.7	19±3.7	58±10	4.2±1.3	2.8±0.9	3.8±0.9	1.04±0.11
Continental island arcs	Dissected magmatic arcs	27±4.5	59±8.2	146±20	11.0±3.6	7.5±2.5	7.7±1.7	0.79±0.13
Continental margin (Andean type)	Uplifted basement	37	78	186	12.5	8.5	9.1	0.60
Passive margins	Craton interior, tectonic highlands	39	85	210	15.9	10.8	8.5	0.56
Hong Hoi Formation (Mean)		20.24	39.43	95.45	10.03	6.62	7.53	NA
Wang Chin Formation (Mean)		22.54	48	113.64	11.52	7.61	8.83	NA

6.5 Sandstone provenance as suggested by feldspar composition

It has widely been suggested that the chemical composition of detrital feldspar can be used in studies of sandstone provenance, since igneous and metamorphic feldspar have different inherent physical and chemical properties (Trevena and Nash, 1981; Helmold, 1985; Pettijohn et al., 1987). Trevena and Nash (1981) have delineated eight feldspar provenance fields in the albite-anorthite-orthoclase ternary diagram from microprobe analyses of feldspar from crystalline rocks. In general, the diagram shows that the maximum potassium content of plagioclase decreases from volcanic to plutonic to metamorphic environments, and plutonic and metamorphic alkali feldspar are potassium rich, whereas in volcanics potassium content varies widely (Helmold, 1985). However, this provenance method is found invalid in this study due to albitization. Plagioclase of all compositions is readily albitized especially at high temperatures (>200°C) and during sea water alteration and burial metamorphism (Dr A J Crawford, pers. comm., 1991). It is therefore suggested that caution should be taken when most plagioclase in sandstones is albite in composition.

Following Trevena and Nash (1981), one hundred and fifty-five analyses of feldspars in sandstones from Hong Hoi and Wang Chin Formations and in limestones from Kang Pla Formation have been made using an electron microprobe. Plagioclase is optically classified into twinned and untwinned types. Plagioclase phenocrysts in microlitic volcanic fragments suggestive of andesine compositions were also analyzed. In addition, a few analyses were also made of plagioclase grains in limestone host. Mean and one standard deviation of feldspar chemical composition from various types in terms of albite, anorthite and orthoclase contents are summarized in Table 6.8.

The analyses show that all types of plagioclase are now albite, even plagioclase phenocrysts in microlitic andesitic volcanics. This indicates widespread albitization, and precludes the use of the Trevena and Nash provenance method. Feldspar fragments in limestones display less alteration than those in sandstones and show andesine compositions (Table 6.8). Potassium rich feldspar (97% Or) can be derived from either plutonic or metamorphic sources (Trevena and Nash, 1981). These potassium feldspars commonly display perthitic texture, suggesting a plutonic rather than metamorphic origin. This interpretation is in agreement with plutonic root of volcanic arcs concluded from the study on framework modes in sandstone composition (see 6.3).

Table 6.8 Mean and one standard deviation of albite, anorthite and orthoclase of feldspar in sandstones from Hong Hoi and Wang Chin Formations and in limestones from Kang Pla Formation, as determined by electron microprobe. Number of analyses given in parenthesis.

	An%	Ab%	Or%
1. Plagioclase grains in sandstones			
• with twinning (52)	1.2±1.9	97.9±3.3	0.9±2.0
• without twinning (23)	2.9±3.4	95.7±4.2	1.5±1.8
• phenocrysts in microlitic volcanics (34)	1.7±2.1	96.1±3.9	2.1±3.0
2. Plagioclase grains in limestone host			
• with twinning (27)	46.4±4.6	51.4±4.4	2.2±0.5
• without twinning (2)	45.4±1.1	51.9±1.1	2.7±0.1
3. Potassium feldspar in sandstones (17)	0.01±0.05	2.9±1.8	97.1±1.7

6.6 Conclusions

Results for the Lampang sandstones strongly imply a volcanic magmatic arc provenance with recycled orogen provenance being common in the upper part of the sequence. Continental block provenance is insignificant.

The Phra That Formation at km 31.7-31.9 on the Lampang-Denchai highway, based on sedimentary structures, is interpreted as being deposited in tidal environments. Their quartzose detritus has a multicycle origin and, is mainly if not all, derived from sedimentary and volcanic sources.

The Hong Hoi sandstones are clearly derived from volcanics, as indicated by their composition and the discriminating ternary plots. The ternary plots further suggest a forearc depositional environment and active magmatic arc sources for the Hong Hoi sandstones. The REE data confirm this interpretation and further suggest that the source volcanics formed in an arc on a thin continental margin which is consistent with their field occurrence.

The Pha Daeng red beds formed in fan delta environments. Sandstones consist of lithic arkose and feldspathic litharenite. Quartz content increases and grain size decreases up the sequences. Sandstones from the lower part of the formation were derived mainly from magmatic arc sources, although the possibility of continental margin source can not be ruled out.

Sandstones of the Wang Chin Formation differ from sandstones of the Hong Hoi Formation in that they have a higher quartz content, more rounded quartz, and less microlitic texture in volcanic fragments. Both formations are lithic arkose to feldspathic litharenite in composition. The ternary plots indicate magmatic arc and uplifted sedimentary sources for the middle Carnian rocks. The uplift may have occurred contemporaneously with tectonic activity in the Pha Daeng Formation. High quartz content in the Wang Chin Formation may partly be due to subdued tectonism allowing intense weathering in source area and resulting more concentration of stable grains (Folk, 1974; Ingersoll and Suczek,1979). During late Carnian and early Norian times, sediments may have been derived from both magmatic arc and recycled orogen sources. The magmatic arc sources, however, increased from late Carnian to early Norian.

Chapter 7 : Tectonic implications and paleogeography of the Lampang Group

7.1 Introduction

There is a longstanding controversy over (1) whether the Lampang Group consists of syn-subductional (e.g., Bunopas, 1981; Bunopas and Vella, 1983; Hada, 1990; Panjasawatwong, 1991; Burrett et al, in press) or post-collisional sediments (e.g., Helmcke, 1982, 1986a; Hahn et al, 1986; Wolfart, 1987; Cooper et al., 1989; Metcalfe, 1990b; Piyasin, 1991), and (2) when the continental collisions between the Shan-Thai and Indochina terranes occurred. At least eight suturing times, from Devonian to Late Triassic Periods, have been proposed for this collision. There is no doubt that the present regional structure of the study area, the Sukhothai fold belt, is the result of several orogenic events of varying intensities that made them geologically complex (Bunopas, 1981; Hahn et al., 1986).

Evidence presented in this thesis from stratigraphy (CH-2), sedimentology (CH-3, 4, 5), and sandstone provenance (CH-6) of the Lampang Group, and from magmatism, metamorphism, geological structure and paleoclimate indicate that the Lampang Group was deposited in forearc basins above westward subduction of the Indochina terrane underneath the Shan-Thai terrane. The collision was probably not strong and occurred during late Triassic Period. It is the purpose of this chapter to clarify this interpretation.

7.2 Stratigraphic, sedimentologic and provenance evidence

7.2.1 Stratigraphy

The basement rocks of the Lampang Group are presumed to be as old as Silurian-Devonian age, on the basis of having higher deformational degree than the presumed Carboniferous and the Permian strata. However, distribution of these pre-

Permian rocks must be less than previously mapped. Many areas of previous Silurian-Devonian and Carboniferous metavolcaniclastic and clastic rocks have recently been reinterpreted as Permo-Triassic volcanics and Triassic clastics, on the basis of fossils (Chaodumrong and Jeumthon, 1985; Charoenpravat et al., 1987). Wolfart (1987) also questioned the existence of the Silurian-Devonian strata and suggested that they may have been Permian. The cover rocks are presumably Jurassic in age on a stratigraphic basis.

The Lampang Group unconformably overlies the "Permo-Triassic volcanics" and both unconformably and conformably overlies Permian strata. The Lower Triassic (Scythian) is represented by *Claraia* and *Ophiceras* (Chonglakmani, 1981), and the Upper Permian is indicated by *Palaeofusulina* (Sakagami and Hatta, 1982 in Fontaine, 1986). The group both conformably and unconformably underlies the Jurassic red beds which formed in extensional basins (Hahn, 1976). The Lampang Group was formed in two sub-basins and consists of seven formations. The relationship among the formations can be simplified as shown in Figure 7.1. All limestone formations may have been formed as large lenticular bodies and have limited distributions. This configuration was possibly a result of high subsidence rate which does not favor carbonate sedimentation.

An allochthonous terrane is a fault-bounded crustal body that has a coherent stratigraphy and is recognized on the basis of stratigraphic, biostratigraphic, paleomagnetic and geophysical data (Kleinspehn, 1988). Lithologically, different terranes have different stratigraphic histories; when two terranes amalgamated their lithostratigraphy become similar.

Figure 7.2 shows correlation of stratigraphic columns of the study area and its adjacent areas including east Burma, northwest Malaysia, western and peninsular Thailand, Loei fold belt and Chanthaburi-Trat areas, with emphasis on the lithology, facies relationships and stratigraphic unconformities.

The wide distribution of late Carboniferous to early Permian glacial marine deposits from northwest Malaysia through east Burma may deserve a special stratigraphic history, as suggested by Cooper et al. (1989).

In Thailand, the transition from Permian to Triassic strata in most places is a stratigraphic hiatus, except in the Lampang, Nan and Chanthaburi- Trat areas where conformable contacts have been reported, although *Otoceras,* the indicator of Permo-Triassic boundary, has not been observed. In the west and peninsular Thailand, there have been no early Triassic fossils reported; there, middle Triassic through Jurassic sediments accumulated continuously. In the Loei fold belt, Indochina terrane, Laos and East Malay~~sia~~a, an age gap between Scythian to upper Carnian occurs (Hahn et al., 1986; Sattayarak et al., 1989; Metcalfe, 1989). In northeast Thailand, the oldest Triassic pre-Khorat strata is Norian in age and unconformably overlain by the Khorat

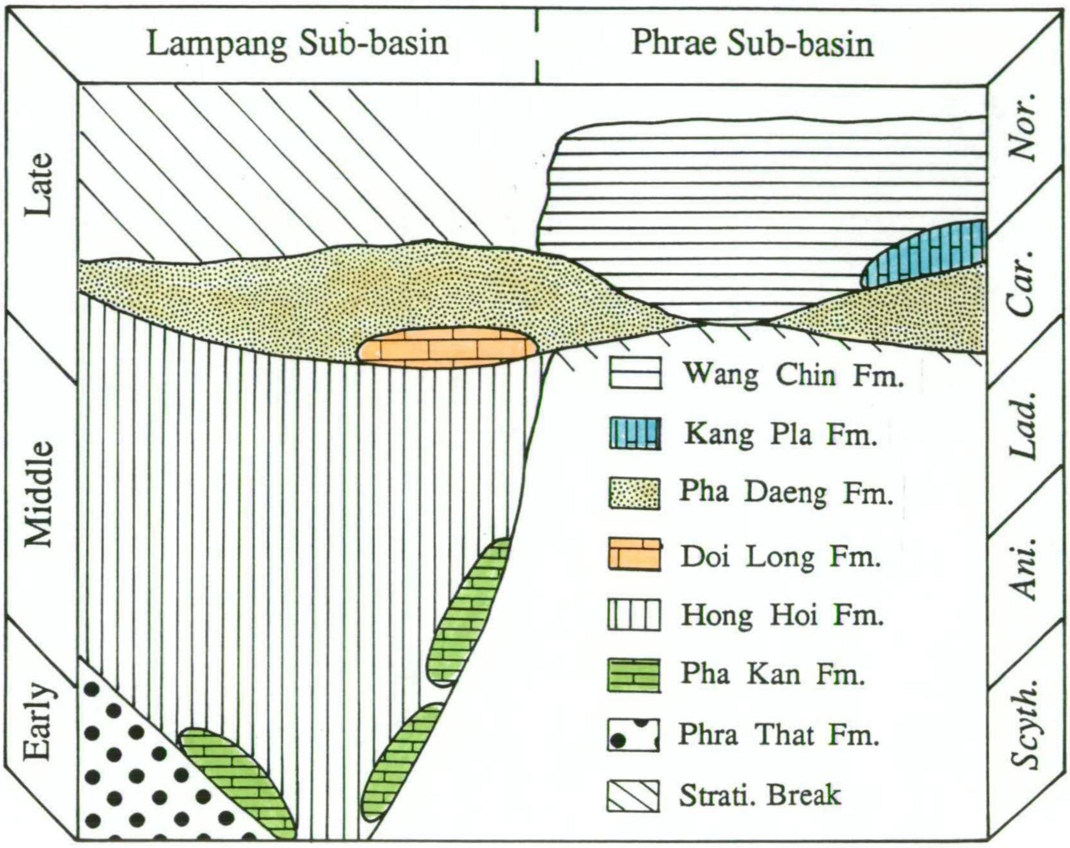
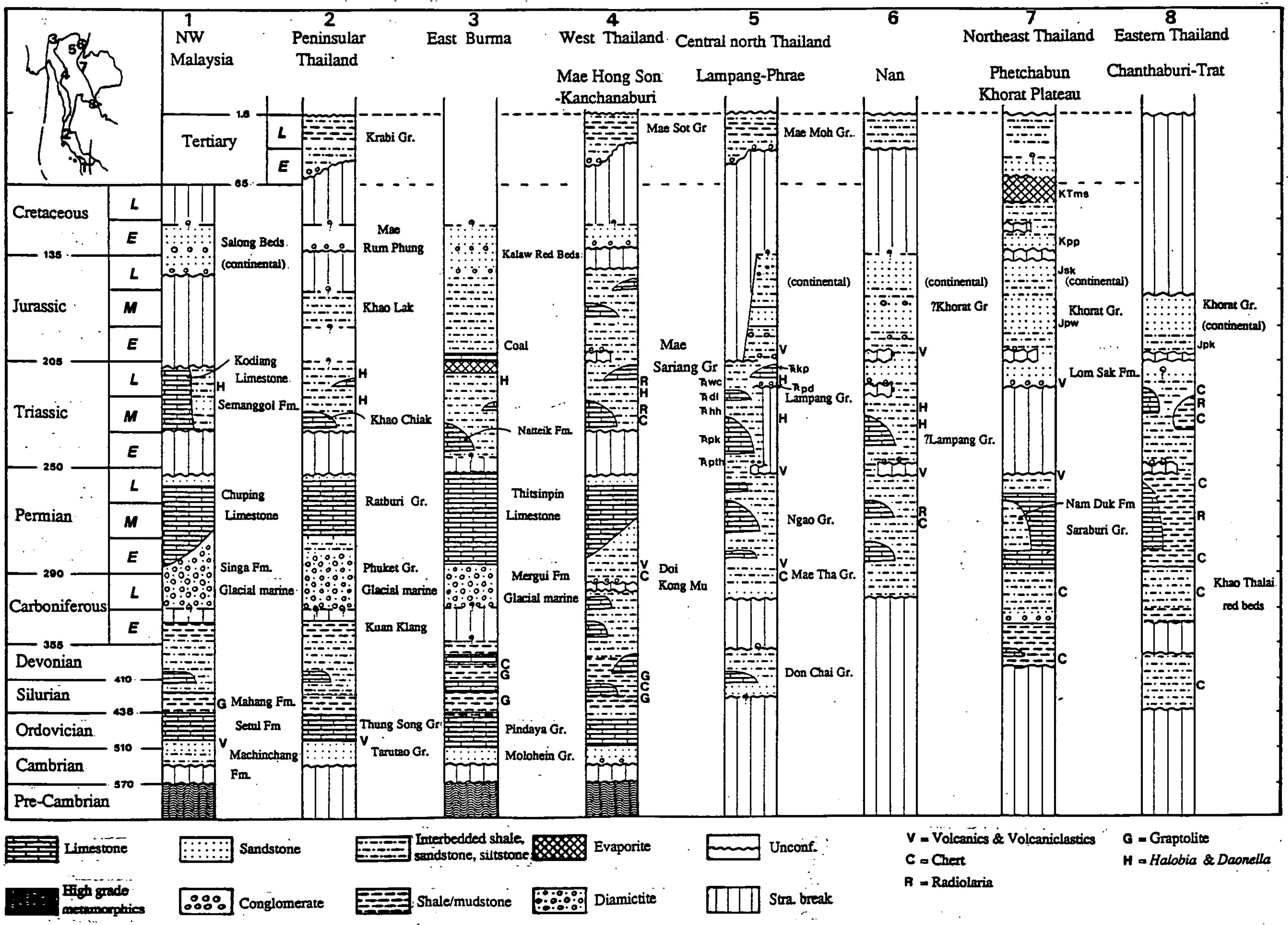


Fig. 7.1 Simplified stratigraphic relationships within the Lampang Group.

Fig. 7.2 Stratigraphic correlation of central north Thailand with adjacent areas including north, west, east, northeast and peninsular Thailand, East Burma and NW Malaysia Note limited distribution of Permian limestone and its lower conformable contacts. Data sources include Bunopas, 1981; Bunopas and Vella, 1983; Fontaine and Suteetorn, 1986; Cooper et al, 1989; Sattayarak et al, 1989; Helmcke, 1982; Chonglakmani and Kenvised, 1985; Hahn et al, 1986; Peng, 1983; Metcalfe, 1989; Cowie and Bassett, 1989; Bender, 1983; V Tansuwan & W Tantiwanich, pers comm., 1991.



1 NW Malaysia
2 Peninsular Thailand
3 East Burma
4 West Thailand
Mae Hong Son -Kanchanaburi
5 Central north Thailand
Lampang-Phrae
6 Nan
7 Northeast Thailand
Phetchabun Khorat Plateau
8 Eastern Thailand
Chanthaburi-Trat
Tertiary
L
E
1.6
65
Cretaceous
135
Jurassic
205
Triassic
250
Permian
290
Carboniferous
355
Devonian
410
Silurian
438
Ordovician
510
Cambrian
570
Pre-Cambrian
M
Salong Beds (continental)
Kodiang Limestone
Semanggol Fm.
Chuping Limestone
Singa Fm. Glacial marine
Mahang Fm.
Setul Fm
Machinchang Fm.
Krabi Gr.
Mae Rum Phung
Khao Lak
Khao Chiak
Ratburi Gr.
Phuket Gr. Glacial marine
Kuan Klang
Thung Song Gr
Tarutao Gr.
Kalaw Red Beds
Coal
Natteik Fm.
Thitsinpin Limestone
Mergui Fm Glacial marine
Pindaya Gr.
Molohein Gr.
Mae Sot Gr
Mae Sariang Gr
Doi Kong Mu
Mae Moh Gr.
(continental)
Lampang Gr.
Ngao Gr.
Mae Tha Gr.
Don Chai Gr.
(continental)
?Khorat Gr
?Lampang Gr.
KTms
Kpp
Jsk (continental)
Khorat Gr.
Jpw
Lom Sak Fm.
Nam Duk Fm
Saraburi Gr.
Khorat Gr. (continental)
Jpk
Khao Thalai red beds
Limestone
Sandstone
Interbedded shale, sandstone, siltstone
Evaporite
Unconf.
High grade metamorphics
Conglomerate
Shale/mudstone
Diamictite
Stra. break
V = Volcanics & Volcaniclastics
C = Chert
R = Radiolaria
G = Graptolite
H = *Halobia* & *Daonella*

Group (Sattayarak et al., 1989). Suteethorn et al. (1988) reported lacustrine or deltaic amphibians of Norian age from the Huai Hin Lat Formation. Similar stratigraphic sequences also occur in Malaysia, 1600 km to the south (Peng, 1983; Metcalfe, 1989), where the Triassic sequences conformably overlie Permian shallow marine sediments only in the Central Basin (comparable to central north Thailand), being absent in the Eastern Belt (comparable to Loei fold belt where only upper Triassic is known), and lower Triassic sediments are apparently absent in the Western Belt (similar to west Thailand) (Fig. 7.2). These long and narrow belts may be a primary feature related to basin geometry, although they also parallel the structure of the Sukhothai fold belt.

7.2.2 Sedimentology

Two large-scale deepening-upward sequences occur in the Lampang Group, indicating a relative sea-level rise which was possibly caused by tectonic rather than eustatic sea-level change, since Triassic glacial deposits are unknown (Embry, 1988). The tectonics were probably related to the interaction between the Shan-Thai and Indochina terranes. The older sequence, ranging in age from early to late Triassic, occurs in the Lampang sub-basin, while the younger is late Triassic in age and occurs in the Phrae sub-basin. Each sequence starts with continental to shallow marine red beds changing upward to carbonate ramp and topped by submarine fan sediments. One difference is that the Lampang sub-basin has also a shallowing-upward sequence at the top. In the Phrae sub-basin, possibly during the late Triassic, its northern part was relatively shallow whereas its southern part contained sediments indicating deeper marine environments. These sequences are similar to those occurring in modern and ancient forearc basins.

Deep-sea sediments, on the basis of radiolarian chert, occurred at least until middle Triassic and have been reported from many places: early to late Permian age from Chanthaburi, late middle to early late Permian from Nan, middle Triassic from south of Chanthaburi and the Nan Suture (Hada, 1990). In the last, red radiolarian cherts occur clasts in a red bed which unconformably overlies serpentinite melange. To the west of the study area, radiolarian chert of late Ladinian to early Carnian age occurs at km 16-17 along the road from Mae Sariang to Mae Hong Son and of late Triassic age occurs at km 49.8 and 51 along the Tak-Mae Sot highway (Fontaine and Suteetorn, 1986).

7.2.3 Petrology and provenance

Sandstones in the Lampang Group consist mainly of volcanic-derived fragments. As shown in chapter 6, the Hong Hoi and Pha Daeng Formations were derived mainly from active magmatic arc sources and accumulated in forearc basins. In the Wang Chin Formation, the source rocks changed to a combination of recycled orogen and magmatic arc sources, possibly as a result of uplifted accretionary prism and/ or of continental collision. Similar sandstone composition to the Wang Chin Formation (km 55.1-55.9) has been reported from the outer-arc high of Nias Island, Indonesia and of Barbados, West Indies (Velbel, 1985). Sandstone petrography further indicates that the Triassic and older plutonic rocks are an insignificant source for sedimentation of the Lampang Group. No high grade metamorphic rock fragments are recognized in the Lampang Group.

Lüddecke et al. (1991) counted the pebbles in conglomerates of the Lampang Group from two locations, one from the Hong Hoi Formation, the other possibly corresponding with the Wang Chin Formation of this study. Their pebble associations are generally similar in composition to those of the sandstones of this study, with volcanic and limestone clast dominated and rare to absent metamorphic and clastic clasts in the former, and metamorphic and clastic clast dominated and rare to absent volcanic and limestone clasts in the latter. They interpreted the conglomerates of the Hong Hoi Formation as having formed in an extensional basin on a continental crust. Extensional basins are, however common in modern forearc areas (Dickinson and Seely, 1979; Karig et al., 1980).

There is a general lack of paleocurrent indicators in the Lampang Group. Although most paleocurrent data came from the Pha Daeng Formation, rare paleocurrent directions in the Hong Hoi and Wang Chin Formations also indicate axial paleoflow (present NNE/SSW). The paleocurrent directions further indicate that there were at least two basins within the Phrae sub-basin (details see CH-5).

7.3 Magmatism, metamorphism, structural and climatic evidence

7.3.1 Volcanic rocks

Four volcanic events occurred in the central north of Thailand (Fig. 7.2): early Permian, Permo-Triassic, late Triassic- early Jurassic and Quaternary. None of these has been radiometrically dated. Tectonic settings of these Mesozoic and Paleozoic volcanic rocks are still being debated, since there are few chemical analyses available.

The Carboniferous- Permian volcanic rocks along the Chiang Mai belt previously interpreted to have formed in an island-arc setting (Macdonald and Barr, 1978) have recently been reinterpreted as continental rift setting within the Shan-Thai terrane (Barr et al, 1990). However, Bunopas (1981, p 419) considered them to have formed in a backarc setting. Hahn et al. (1986) also used the interpretation of Macdonald and Barr (1978) to support their Devono- Carboniferous Variscan Orogeny.

The Permo- Triassic volcanic rocks are intermediate to felsic in composition and crop out parallel to the Nan Suture, in the area between Lampang and Phrae; some in the central north of Thailand may be younger. These volcanic rocks have been considered to be a magmatic arc above a westward dipping subduction zone (Bunopas, 1981; Bunopas and Vella, 1983; Hutchison, 1989). Similar volcanics also occur in the western flank of the Khorat Plateau, to the south, where the volcanics, previously considered to be Permo-Triassic, have recently been $^{40}Ar/^{39}Ar$ dated to be early Triassic and as young as Tertiary (Intasopa et al., 1990). In the Nan Suture, the mafic and ultramafic rocks are an oceanic association interpreted chemically as having formed in ocean- island, backarc and island- arc settings, prior to the late Triassic collision (Panjasawatwong, 1991). The "Silurian-Devonian volcanic and volcaniclastic rocks" at Sirikit Dam near the Nan Suture have recently been found to be intercalated with Permian limestone containing fusulinids (Dr. Yuenyong Panjasawatwong, pers. comm., 1991). Lüddecke et al. (1991) concluded that there are Triassic subduction related volcanics in Nam Pat- Sirikit Dam area.

Upper Triassic- lower Jurassic volcanics occur locally in the Phrae, Phayao and Nan areas (Piyasin, 1972; Hahn, 1976). This is to the east and northeast of the Permo- Triassic volcanic rocks (above). They are intermediate to felsic in composition and associated with nonmarine red beds. Bunopas (1981, p 666-667) showed that they are more alkaline than the Permo- Triassic volcanics, possibly indicating an intra-plate origin.

7.3.2 Plutonism

In general, granitoid rocks in Thailand can be divided into three north-south trending provinces, namely eastern, central and western provinces (Cobbing et al., 1986; Mahawat et al., 1990; Barr and Macdonald, 1991). The area of study is located in the eastern province which includes Carboniferous to late Triassic I-type granites (Mahawat et al., 1990): The central province consists largely of Permian to late Triassic S-type granite batholiths and plutons and associated metamorphic rocks including migmatite, orthogneiss, paragneiss and mylonites (Cobbing et al., 1986;

Barr and Macdonald, 1991). The western province is characteristically of Cretaceous plutons of mixed I- and S-type granites.

The occurrence of late Triassic I- and S-type ganites in the eastern and central provinces, respectively, favors westward subduction and late Triassic collisional model, since I-type granites are generally considered to be a result of subduction-related tectonic setting, whereas S-type granites are contributed to collision-related tectonic setting (Cobbing et al., 1986; Mahawat et al., 1990).

7.3.3 Metamorphism

Sediments of the Lampang Group are unmetamorphosed; the Permian strata are in anchimetamorphic zone; and Don Chai Group of presumably Silurian-Devonian in age is of low metamorphic grade.

A few metamorphic rocks have been radiometrically dated, although considerably more dates are required to make any sound interpretation. As a result, three metamorphic ages have been suggested in the Nan Suture:

1) Devono- Carboniferous: K/Ar age of 344±22 Ma from metamorphosed ultrabasic rocks (interpreted as a result of continental collision between Shan-Thai and Indochina terranes by Helmcke, 1985), and a very good plateau $^{40}Ar/^{39}Ar$ age of 356 Ma from amphibole (Y Panjasawatwong, pers. comm., 1991),

2) Early Permian: K/Ar age of 269±12 Ma for actinolite from the mafic schists of the Pha Som Group, interpreted as a minimum metamorphic age by Barr and Macdonald, 1987), and

3) Cretaceous: a very good plateau $^{40}Ar/^{39}Ar$ age of 97±0.7 Ma from gabbro (interpreted as a result of transcurrent faults, Y Panjasawatwong, pers. comm., 1991). Moreover, Lüddecke et al. (1991) reported that the cleavage in the "Silurian-Devonian phyllites" at the Sirikit Dam- Nam Pat area has a K/Ar metamorphic age of middle Cretaceous and this cleavage is also present in the Triassic strata. Recently, Macdonald et al. (1991) proposed that the high-grade metamorphic rocks, previously interpreted as Precambrian crystalline basement, in Chiang Mai area to the west of the study area are a result of Cretaceous to Paleogene metamorphic core complex similar in origin to those of north America.

7.3.4 Structure and deformation

Thailand can be divided into three major geological features, namely the Shan-Thai terrane including the Sukhothai fold belt in the west, the Indochina terrane including the Loei fold belt in the east and the Nan Suture connecting the two terranes. However, these features have been named differently as tabulated in Table 7.1.

Table 7.1 Showing various names applied to similar terranes and major geological features in Thailand by various authors

<table>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>References</th></tr>
<tr>
<td rowspan="2">•Shan-Thai terrane[1,10,7,15,22]
•Shan-Thai Block[2,3,4,5,16,17,23]
•Shan-Thai Craton[6,9,21]
•Shan-Thai Paraplatform[8,13]
•Sibumasu[18]
•Sinoburmania[19]
•Sinoburmalaya[20]</td>
<td>•Sukhothai fold belt 1-13,15,21
•Sukhothai terrane[22]</td>
<td rowspan="2">•Nan Suture[1,17,21]
•Nan Geosuture[3-5]
•Nan- Uttaradit Suture[9]
•Nan- Uttaradit- Sa Kaeo Suture[2,22]
•Uttaradit- Nan Ophiolite[8,13]
•Nan- Chanthaburi Suture[7]
•Nan River suture[10]</td>
<td rowspan="2">•Loei fold belt[1,3-6,8,13,21]
•Petchabun fold belt[9]
•Loei- Petchabun fold belt[17]
•Phetchabun zone[22]</td>
<td>•Indochina terrane[1,7,10]
•Indochina Craton[6,9,21]
•Indochina Block[3,4,5,17,23]
•Indochina Plate[11]
•Indosinian Block[2]
•Indosinian Craton[9]
•Khorat Kontum Platform[8,13]
•Indosinian microplate[14]
•Indo-China terrane[15,18]
•Indosinian terrane[22]</td>
<td rowspan="4">1= This study
2= Barr & Macdonald, 1987
3= Bunopas & Vella, 1978
4= Bunopas, 1981
5= Bunopas & Vella, 1983
6= Chuaviroj, 1990
7= Hada, 1990
8= Hahn et al., 1986
9= Helmcke, 1984, 1986 a, b
10= Singharajwarapan & Berry, 1991
11= Piyasin, 1991
12= Workman, 1975
13= Wolfart, 1987
14= Chonglakmani, 1982
15= Burrett et al (in press)
16= Fontaine & Suteetorn, 1986
17= Cooper et al., 1989
18= Metcalfe, 1988
19= Gatinsky et al., 1984</td>
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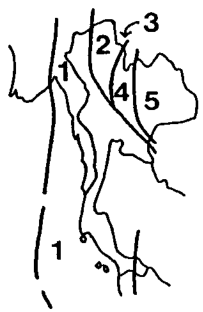
<td></td>
<td>20= Gatinsky & Hutchison, 1986
21= Panjasawatwong, 1991
22= Barr&Macdonald, 1991
23= Fontaine, 1986</td>
</tr>
<tr>
<td colspan="2">Shan-Thai including Sukhothai fold belt[1,3,4,5]</td>
<td></td>
<td colspan="2">Indochina including Loei fold belt[1,3,4,5,22]</td>
</tr>
<tr>
<td></td>
<td colspan="3">Yunnan Malay Mobile Belt[6,8,13]</td>
<td></td>
</tr>
</table>

Pre-Triassic strata both in Sukhothai and Loei fold belts including Upper Permian carbonate in western Kampuchea exhibit eastward verging folds (Bunopas, 1981; Hahn et al., 1986), and on this basis the westward subduction of Indochina terrane underneath the Shan-Thai terrane is favored in this study. Eastward vergence also present in the Mesozoic strata of Nan area (Sukvattananunt and Assavapatchara, 1987, p 18; Lumjuan and Sinpun-Anunt, 1987).

The Lampang Group forms an open-folded structure with east dipping axial plane, and exhibits one deformational phase, except where it is in contact with the transcurrent fault. Whereas the underlying Permian strata contains isoclinal folds and has an extra cleavage. However, Chantaramee et al. (1980) reported two generations of very large scale folds in the Lampang sub-basin (Mae Chang reservoir). Singharajwarapan and Berry (1991) considered the open folds in the Lampang, Phrae and Sirikit Dam areas to be a result of the collision between Shan-Thai and Indochina terranes. Figures 7. 3 and 7.4 show geological cross sections of mainly upper Triassic strata along the Lampang-Denchai and Rong Kwang- Ngao highways, respectively. The strata show open folds with slightly westward tectonic transpose. The overturned strata claimed by Macdonald (1977) are not recognized in this study.

To the south in eastern Thailand, Burrett et al. (in press) reported that strongly deformed upper Triassic strata with one phase of steeply plunging folds unconformably overlies an extra deformational phase of Permian strata, and unconformably underlies the undeformed Lower Jurassic- Cretaceous sediments of continental Khorat Group.

Table 7.2 is a comparative chart of the tectonic events in Thailand, interpreted by various authors. Four tectonic events, during Permian to Tertiary, are recognized in the central north of Thailand: Permo- Triassic (Indosinian I), late Triassic (Indosinian II), middle Cretaceous, and Tertiary (Himalayan). The term "Indosinian" orogeny here follows the definition of Workman (1975) who proposed this term for tectonic movements that occurred during early Triassic to Liassic time in southeast Asia.

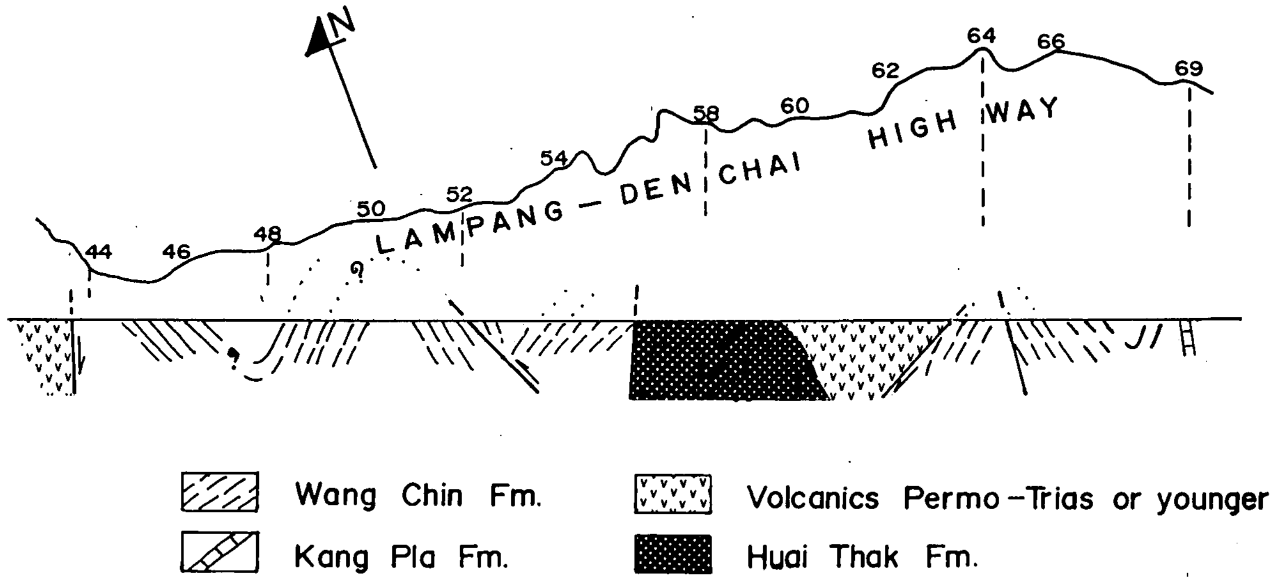


Fig. 7.3 Simplified geologic cross section along the Lampang-Denchai highway. Note the sequences represent mainly the upper part of the Lampang Group, and the highway route was constructed by hand compass. Numbers denote kilometer posts.

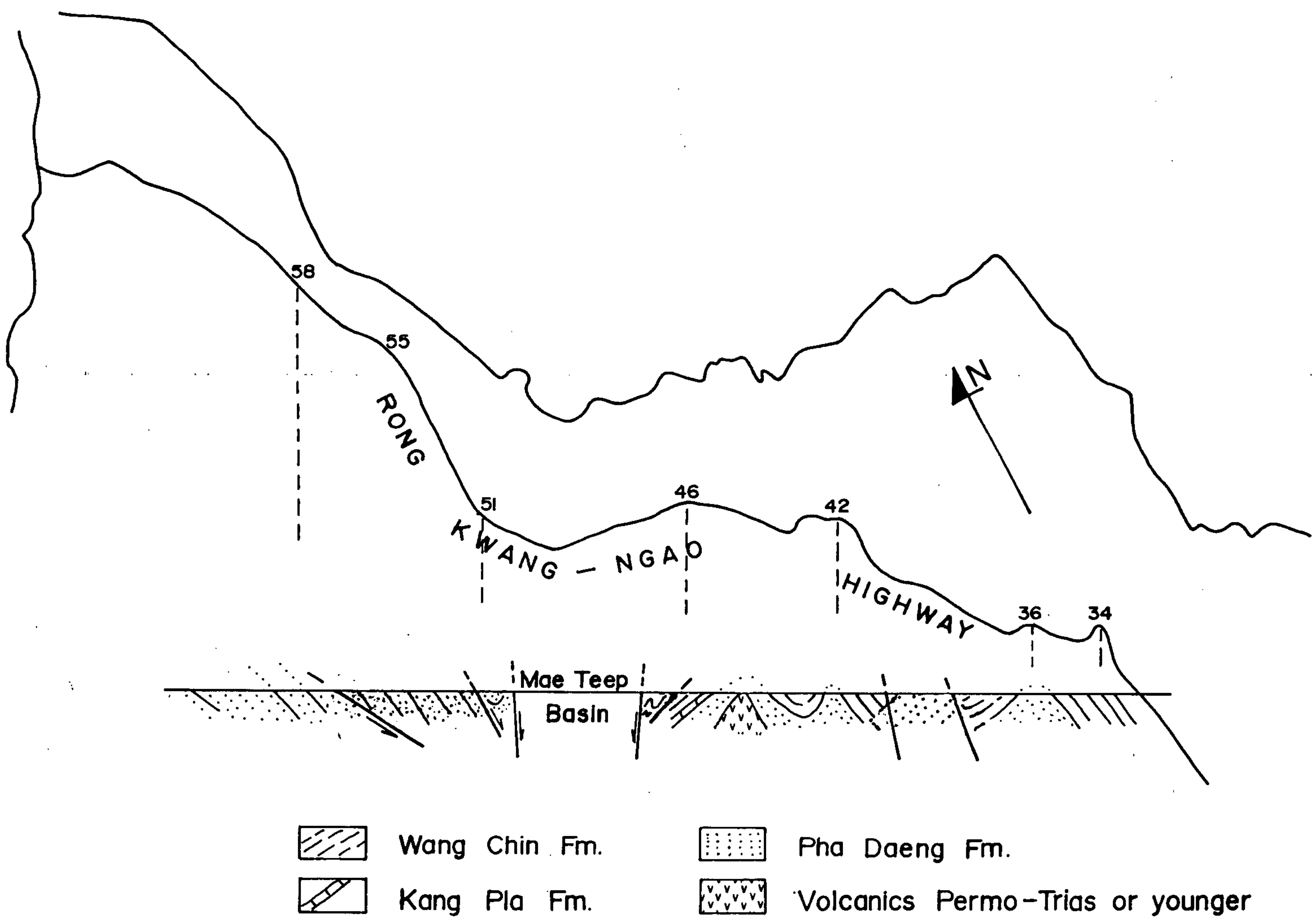
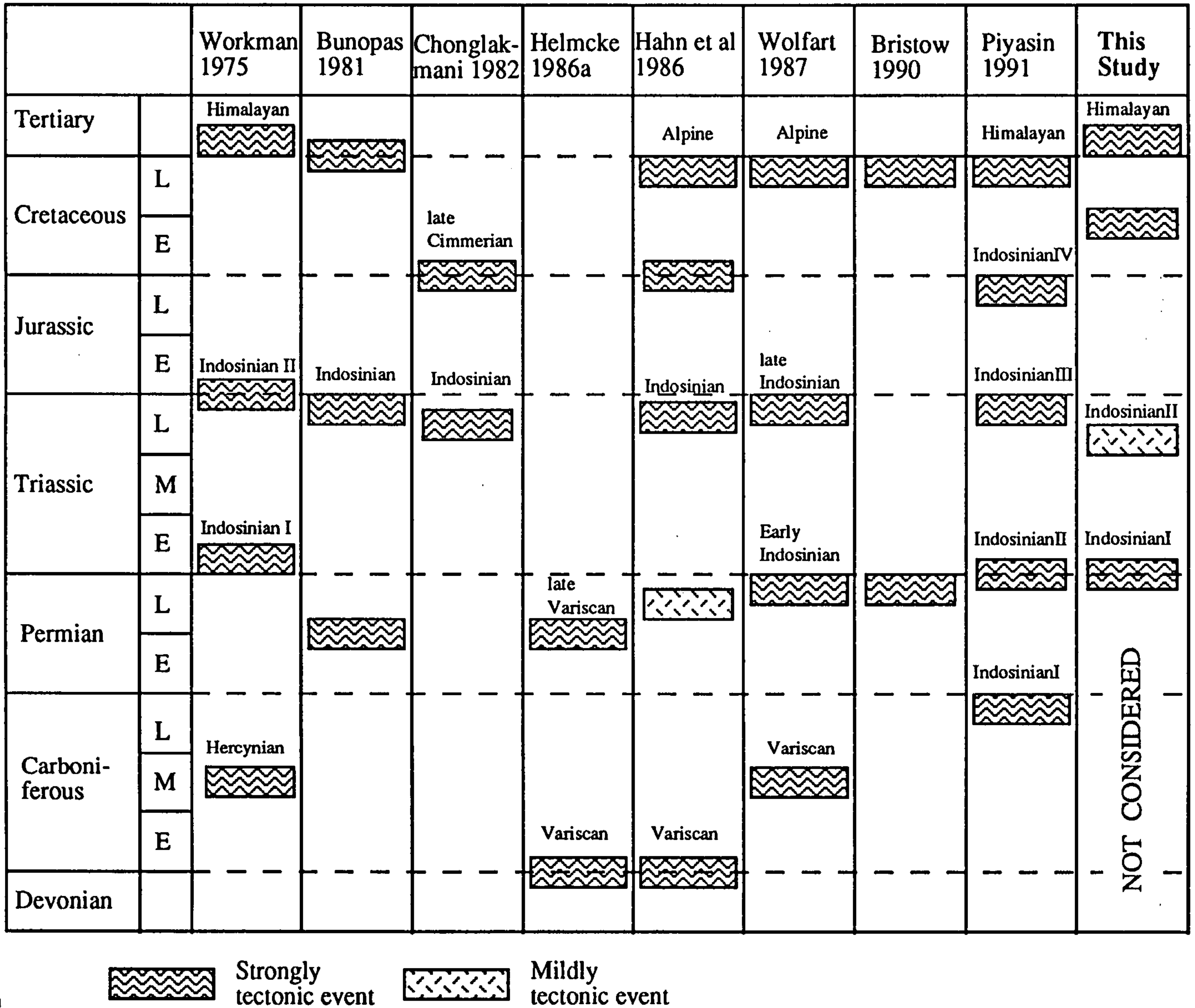


Fig. 7.4 Simplified geologic cross section along the Rong Kwang-Ngao highway. Note the sequences represent mainly the upper part of the Lampang Group, and the highway route was constructed by hand compass. Numbers denote kilometer posts.

Table 7.2 Interpretation of tectonic events in Thailand by various authors



7.3.6 Climate and paleogeography

Table 7.3 shows the evolution and interpretation from various authors of suturing and rifting time for the Shan-Thai terrane and its counterparts and also for the Indochina and South China terranes.

It is generally agreed that both Shan-Thai and Indochina terranes are fragments of the Gondwana from the Southern Hemisphere (e.g., Burrett, 1974; Bunopas, 1981; Metcalfe, 1990b), although opinions on rifting time vary (Table 7.3). The Shan-Thai terrane was adjacent to the NW Australian part of the Gondwana until early Permian, as indicated by the wide distribution of Upper Carboniferous to Lower Permian glacial marine sediments (Phuket Group and Kangkrachan Fm in Thailand, Singa Fm in NW Malaysia and Mergui Fm in east Burma- see Fig. 7.2) (Burrett and Stait, 1985; Metcalfe, 1989; Sashida et al., 1991; Burrett et al., in press).

The Permian strata of north Thailand differ from those of peninsular Thailand and Malaysia in that the latter were deposited in a cold climate regime during early Permian on the basis of fossils (Waterhouse, 1982) and geochemistry (Rao, 1988), and are rare in Middle Permian fusulinid *Neoschwagerina*, *Verbeekina* and *Sumatrina* and Upper Permian fusulinids *Palaeofusulina* (Fontaine and Suteetorn, 1986). However, Metcalfe (1989) noted the occurrence of the *Palaeofusulina* in the Central Basin, Malaysia. Fontaine and Suteetorn (1986) stated that during late middle to middle late Permian (Murgabian to Dzhulfian), the Shan-Thai and Indochina terranes had different paleogeographic positions, on the basis of rare fusulinine and coral in the former.

During middle to late Triassic, the central north and west of Thailand, west Malaysia and east Burma were possibly the same paleogeographic province, as indicated by wide distributions of bivalves *Halobia* and *Daonella*, (Fontaine and Suteetorn, 1986) and foraminifera *Aulotortid* assemblages (Vachard, 1986).

Paleomagnetically, the Shan-Thai terrane was located at 30°S in Permian, 15° S in late Triassic and 20° N during late late Triassic to late Jurassic (Bunopas, 1981; S Bunopas, pers comm., 1990). The placement of the Shan-Thai terrane during Triassic is supported by the occurrence of ooids in the Lampang Group, since ooids are suggestive of warm-water rather than cold-water limestones (Rao, 1981).

Table 7.3 Summary of the variety of opinions on the timing of suturing and rifting events between the Shan-Thai and its associated terranes

Shan-Thai vs **Gondwana** (rifting)	**Shan-Thai** vs **Western Burma** (convergent)	**Shan-Thai** vs **Indochina** (convergent)	**Indochina** vs **South China** (convergent)
•**Early Carboniferous** (Bunopas, 1981; Bunopas & Vella, 1983) •**Early Permian** (Shi & Waterhouse, 1991) •**Permian** (Burrett et al., in press) •**late Early Permian** (Metcalfe, 1990b, 1991) •**Late Permian** (Sengör et al., 1988) •**Late Jurassic** (Audley-Charles, 1988)	•**Cretaceous** (Hahn et al., 1986; Metcalfe, 1990b) •**Late Cretaceous- Early Tertiary** (Cooper et al., 1989)	•**Devono-Carboniferous** (Hahn, 1984; Hahn et al., 1986; Helmcke 1986a, b; Alterman, in press) •**Middle to Late Carboniferous** (Wolfart, 1987) •**Middle Permian** (Hemcke & Lindenberg, 1983; Helmcke, 1985) •**Late Permian** (Burton, 1984; Harbury et al., 1990) •**Late Permian to Early Triassic** (Hayashi, 1989; Piyasin, 1991) •**Early Triassic** (Thanasuthipitak, 1978; Cooper et al., 1989; Metcalfe, 1990b) •**Middle Triassic** (Bunopas & Vella, 1983; Bunopas, 1985; Chuaviroj, 1990) •**Late Triassic** (Bunopas & Vella, 1978; Gatinsky et al., 1978; Asnachinda, 1978; Macdonald & Barr, 1978; Bunopas, 1981; Chonglakmani, 1981; Hahn, 1982; Sengör, 1984; Gatinsky & Hutchison, 1986; Metcalfe, 1988, 1989; Hutchinson, 1989; Hada, 1990; Panjasawatwong, 1991; Burrett et al., in press)	•**Carboniferous** (Gatinsky et al., 1984) •**Middle Carboniferous** (Metcalfe, 1990b) •**Triassic** (Hahn, 1984) •**Middle Triassic** (Bunopas & Vella, 1983; Chuaviroj, 1990) •**Late Triassic** (Bunopas, 1981; Sengör, 1984; Sengör et al., 1988; Cooper et al., 1989) •**Cretaceous** (Workman, 1975)

7.4 Discussion

The geological history of central north Thailand and indeed of Southeast Asia as a whole is complex and involved many tectonic events. Opinions vary as to the timing of suturing between the Shan-Thai and Indochina terranes and to depositional setting of the Lampang Group. Whether it is a syn-subductional or post-collisional related basin is contentious. Table 7.4 shows five different suggested suturing times. Figure 7.5 also depicts five different tectonic models for Thailand, particularly during late Permian to late Triassic time. Modern and well-known ancient subduction systems show that they last long and can be reactivated (Aleutian Arc, Alaska = Oligocene to present, Stewart, 1978; Stikine terrane, western Canada = late Triassic to early Jurassic, Eisbacher, 1981; Sunda Arc, Indonesia = Oligocene to present, Hamilton, 1988).

The difference in deformational styles is obvious among the following: highly deformed greenschist presumably Silurian- Devonian in age, isoclinal folded anchimetamorphosed Permian strata, open folded unmetamorphosed Triassic Lampang Group, and broad folded Jurassic Khorat Group. These differences are always used as hard evidence by all models. Some models (e.g., Bunopas, 1981; Bunopas and Vella, 1983; Panjasawatwong, 1991; Barr and Macdonald, 1991) proposed arc-continental collision to explain these differences, prior to late Triassic continent-continent collision. Other models (e.g., Helmcke, 1986a; Hahn et al., 1986; Altermann, in press) have taken the Devono-Carboniferous metamorphic age to indicate the major collision. As mentioned in 7.3.3, there are at least three metamorphic ages in the Nan Suture. More age data, not only from Nan and Chanthaburi areas but also from Malaysia, are needed to clarify their regional sense. However, Professor Dr Helmcke has apparently abandoned this notion as his recent work (Lüddecke et al., 1991) considers that Triassic subduction occurred.

Table 7.4 Summary of opinions on the timing of suturing between Shan-Thai and Indochina terranes

Suturing time	Advocators	Their grounds
Devono-Carboniferous	Altermann et al., 1983, in press; Helmcke, 1986a; Hahn et al., 1986	difference in deformational styles between highly deformed Middle to Upper Devonian and mild deformed Lower Carboniferous (Visean) limestone; metamorphic age of basic & ultrabasic rocks of 344±22 Ma; compared with Variscan orogeny
Middle to Late Carboniferous	Wolfart, 1987	difference in metamorphic grade among metamorposed Silurian-Lower Carboniferous Don Chai Group, anchimetamorphosed Permian and unmetamorphosed Triassic Lampang Group; lesser deformation of post-Paleozoic strata; compared with Variscan orogeny
Middle Permian	Helmcke & Lindenberg, 1983; Helmcke, 1982, 1984, 1985, 1986a	difference in deformational styles between more highly deformed Middle Permian clastic flysch with eastward vergence, and less strongly deformed limestone molasse of Murgabian to Midian age from Indochina terrane; compared with late Variscan orogeny
Late Permian to Early Triassic	Thanasuthipitak, 1978; Cooper et al., 1989; Sattayarak et al., 1989; Hayashi, 1989; Harbury et al., 1990; Metcalfe, 1990b, 1991; Piyasin, 1991	difference in deformational styles between isoclinally folded Permian and open-folded Triassic; Permian limestone block in the melange in Malaysia; I-type granite of 260 Ma & S-type of 200-230 Ma; wide distribution of Permian limestones on both the Shan-Thai and Indochina; no Triassic orogenic compression
Late Triassic	Bunopas & Vella, 1978; Gatinsky et al., 1978; Asnachinda, 1978; Macdonald & Barr, 1978; Bunopas, 1981; Mitchell & Garson, 1981; Chonglakmani, 1981; Sengör, 1984; Hutchinson, 1989; Metcalfe, 1989; Hada, 1990; Panjasawatwong, 1991	difference in deformational styles between open-folded Triassic and broadly folded Jurassic Khorat Group; Middle Triassic radiolarian chert in the Suture at Nan & Chantaburi; inferred Jurassic red beds overlie the Nan serpentinite melange; east vergence of inferred pre-Permian strata

Fig. 7.5 Showing various tectonic models during Permian and Triassic for Thailand including interpretations of suturing time;

A) Late Triassic collision by Bunopas (1981)

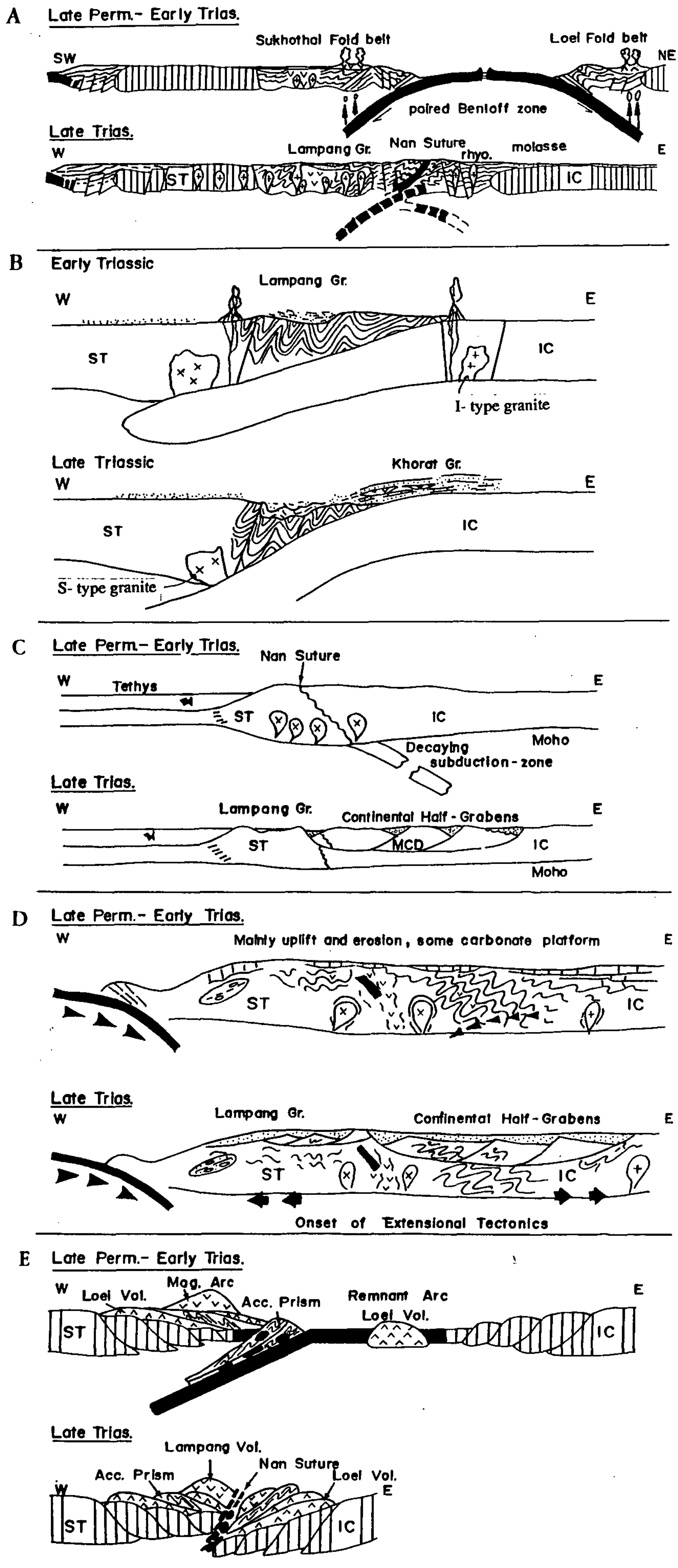
B) Middle Permian collision by Helmcke (1982)

C) Early Triassic collision by Cooper et al. (1989)

D) Devono-Carboniferous collision by Altermann (in press), and

E) Late Triassic collision by Panjasawatwong (1991).

Note ST = Shan-Thai terrane, IC = Indochina terrane.



A
Late Perm.- Early Trias.
Sukhothai Fold belt
Loei Fold belt
SW
NE
paired Benioff zone
Late Trias.
W
Lampang Gr.
Nan Suture
rhyo.
molasse
E
ST
IC
B
Early Triassic
Lampang Gr.
W
E
ST
IC
I- type granite
Late Triassic
Khorat Gr.
W
E
ST
IC
S- type granite
C
Late Perm.- Early Trias.
Nan Suture
W
Tethys
E
ST
IC
Moho
Decaying
subduction-zone
Late Trias.
W
Lampang Gr.
Continental Half-Grabens
E
ST
MCD
IC
Moho
D
Late Perm.- Early Trias.
W
Mainly uplift and erosion, some carbonate platform
E
ST
IC
Late Trias.
W
Lampang Gr.
Continental Half-Grabens
E
ST
IC
Onset of Extensional Tectonics
E
Late Perm.- Early Trias.
W
Loei Vol.
Mag. Arc
Acc. Prism
Remnant Arc
Loei Vol.
E
ST
IC
Late Trias.
Lampang Vol.
Nan Suture
Acc. Prism
Loei Vol.
W
E
ST
IC

The present study of sandstone provenance and facies associations indicates that the Lampang Group was deposited in forearc basins and thus favors the late Triassic collisional model. Furthermore, this interpretation is consistent with the wide occurrence of collision-related late Triassic S-type granites in the Central Province to the west, and the occurrence of middle Triassic radiolarian chert in the Nan Suture to the east, although the late Triassic deformation is also considered as a mildly orogenic compression. Sandstone compositions of the Hong Hoi Formation argue strongly against deposition in either successor and foreland basins (details see CH-6) and further indicate that source rocks shifted from mainly magmatic arc for the Hong Hoi Formation to a combination of magmatic arc and recycled orogen for the Wang Chin Formation. This change, based on the ages of the Pha Daeng and Wang Chin Formations, possibly occurred during the middle Carnian and may have been related to interaction between the Shan-Thai and Indochina terranes. This view is consistent with the "Adjacent Basin" model which is overwhelmingly supported by stratigraphic and sedimentologic evidence (details see CH-2).

The absence of coarse-grained facies in the Hong Hoi and Wang Chin Formations makes it difficult to ascertain whether it has been eroded, concealed or has never existed. The stratigraphy of the Lampang Group may be similar to those of the Central Basin, Malaysia. There, the basin is extensional and bounded on both sides by olistostrome (Metcalfe, 1989). Chonglakmani et al. (1991) stated that sedimentation in central north Thailand (between Lampang and Denchai) was controlled by extensional tectonics. The occurrence of conglomerates and limestone conglomerates of the Pha Daeng Formation argues against strike-slip or oblique sedimentation, since the sediments occur adjacent to their parent rocks, and thus there are no mismatch sequences.

Modern occurrences of forearc basins show that they contain sediments ranging in facies from deep marine to continental, being deposited in compressional, extensional and strike-slip basins, and having depocenters of successively younger stratal packages being displaced arcward (Dickinson and Seely, 1979; Karig et al., 1980; Reading, 1980; Leggett, 1982; Hamilton, 1988; Ryan and Scholl, 1989).

Figure 7.6 shows the evolution of the Triassic basin in Thailand, particularly in the central north area. Four evolutionary stages can be discerned:

1) During late Permian to early Triassic Period: An ocean separated the Shan-Thai from the westward subducting Indochina terranes. Continental to shallow marine clastic sediments occurred widely in the Lampang sub-basin, covering Ban Tha Si, Sop Prap, Chae Hom, Phrao, and west of Ngao and Phayao. In many places, sedimentation was continuous from late Permian to early Triassic. Patch reefs occurred locally on topographic highs. In Nan area to the east, Chonglakmani (1981) reported an occurrence of deep marine sediments throughout the Triassic Period.

2) During middle Triassic Period: The Lampang sub-basin was formed as an intramassif basin, similar to that of Dickinson and Seely (1979). Shallow marine clastic sediments accumulated continuously in the Lampang sub-basin, with an increasing amount of carbonate and deep marine sediments. The Mae Sariang Group may have formed during this stage as a foreland basin. However, much more data are needed to confirm the origin of the Mae Sariang Group. Deep-sea sediments were deposited in the Mae Sariang and Nan areas (Fontaine and Suteetorn, 1986; Hada, 1990). The Loei fold belt and Khorat Plateau may have been subaerially exposured, since there have been no middle Triassic sediments in those areas.

3) During early late Triassic Period: Deep-sea sediments occurred widely in both Lampang and Phrae sub-basins. Sedimentation rate was possibly high, as suggested by lack of substantial bioturbation and limited distribution of limestones. However, lack of substantial conglomerates argues against high topographic relief. The collision between Shan-Thai and Indochina terranes started. As a result, the Lampang sub-basin continued to be uplifted simultaneously with the occurrence of outer-arc high and the Phrae sub-basin. The latter is underlain by strata similar to those described as accretionary complexes by Singharajwarapan and Berry (1991) and thus formed as a constructed basin, similar to that of Dickinson and Seely (1979). The uplift may have been related to basement duplexing and underplating of subducting sediments similar to those explained in the Aleutian forearc, USA (Ryan and Scholl, 1989). There is also an occurrence of collisional related S-type granites.

4) During late Triassic Period: Deep-sea sediments occurred only in the Phrae sub-basin, and eventually led to an extinction of sea in the central north of Thailand. The continental collision was apparently mild. The possibility for oblique collision is open. The occurrence of the late Triassic extensional basins in northeast Thailand may have taken place not long after the Phrae sub-basin (also see Fig. 7.2). In west Thailand, marine sedimentation continued until the Jurassic Period.

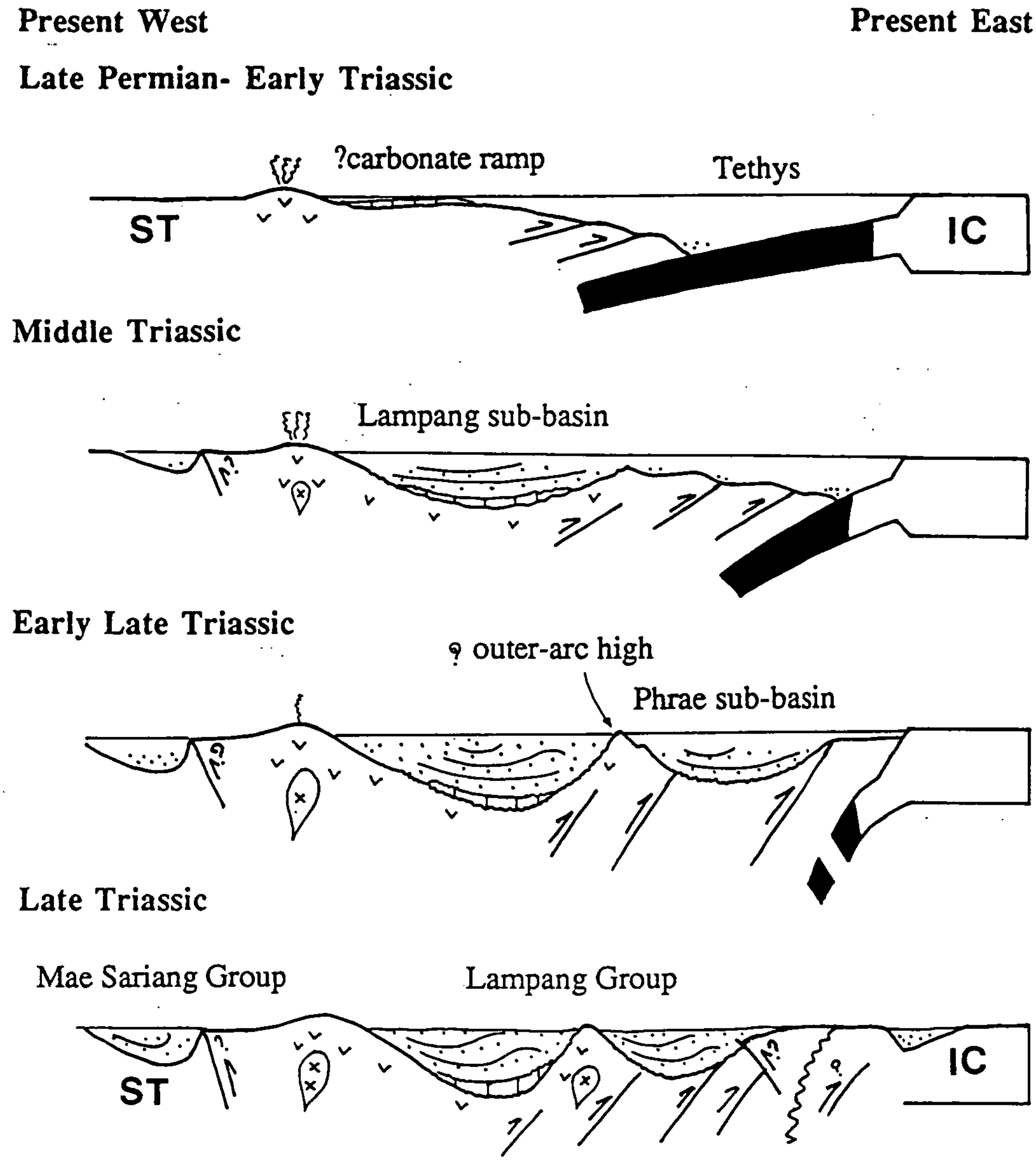


Fig. 7.6 The evolution of the Lampang Group and other Triassic basins in Thailand; cross symbol = granite, V = Lampang volcanics, stipple = Triassic sediments, ST = Shan-Thai terrane, IC = Indochina terrane, solid black = oceanic crust.

Conclusions

Stratigraphy

A reinvestigation and revision of the stratigraphy of the Lampang Group is essential, not only because of new field evidence but also because previous classifications are irreconcilable. In order to unravel these problems, twenty-four representative stratigraphic sections were measured and hundreds of reconnaissance localities were also investigated.

It has long been known (Piyasin, 1972) that the Lampang sub-basin in the west contains a deepening-upward megasequence, changing from red beds to carbonates and marine turbidites, and this is followed, conformably, by a shallowing-upward megasequence, represented by a change upward from marine turbidites to carbonates and red beds, whereas the Phrae sub-basin in the east contains only the deepening-upward megasequence. The main argument is the stratigraphic placement of the sequence in the Phrae sub-basin; those in the Lampang sub-basin are generally accepted.

Evidence from stratigraphy, sedimentology and paleontology clearly shows that the red beds of the Phrae sub-basin corresponds well with the upper red beds or Pha Daeng Formation of the Lampang sub-basin (e.g., similar age, lithology and depositional environments) rather than with the lower red beds or the Phra That Formation as in previous classifications. Recent work of Chonglakmani and Kenvised (1987a, b) is consistent with this interpretation. Thus, the stratigraphy of the Phrae sub-basin deserves a different stratigraphic placement that overlaps those in the Lampang sub-basin. The bivalves *Halobia* often taken for granted as Hong Hoi criteria in fact belongs to the Wang Chin and Pha Daeng Formations. Names of the formations of the Lampang Group proposed here appear not only to compromise the contradictory names of the previous classifications but they also follow the rule of the international stratigraphic guide as well.

The Lampang Group is dominantly fine-grained, consisting of seven formations and where appropriate the member divisions are also provided. The Pha Daeng is the only formation that is widespread over both sub-basins. Time equivalence among the formations is common. In most areas, the group unconformably overlies the inferred Permo-Triassic volcanics. It both unconformably and conformably overlies and underlies the Permian strata and the red beds of possibly Jurassic age, respectively. The Lampang sub-basin ranges in age from Scythian to middle Carnian, having a maximum thickness of 3000 m, whereas the Phrae sub-basin contains fossils of middle Carnian to early Norian ages and has a maximum thickness of 2000 m.

The limestone formations (Pha Kan, Doi Long and Kang Pla) apparently formed in relative narrow and limited areas, where they did not develop their contiguous formations may be joined. Such occurrences are shown in the field by conformable contacts between the Hong Hoi and Pha Daeng Formations or the Pha Daeng and Wang Chin Formations. In such cases the gray beds on top of the red beds belong to the overlying gray-beds formation, i.e., either Hong Hoi or Wang Chin Formation.

Sedimentology

The microfacies of limestones of the Pha Kan, Doi Long and Kang Pla formations were investigated. As a result, fourteen microfacies were proposed, representing three main depositional environments, i.e., ramp platform, drowned ramp and regressive platform. The ramp platform is dominated by microfacies of oncolitic wackestone to lime mudstone (C1), oncolitic peloidal packstone (C2) and skeletal grainstone (C12). The first two microfacies dominate in the Wiang Sawan and Muang Kham Members of the Pha Kan Formation, while the last microfacies is common in the Kang Pla Formation. The drowned ramp and regressive platforms contain mostly "pure" carbonates, i.e., little in mud content,indicating that they may have been formed distant from siliciclastic influx. The former, represented by the Cave Temple Member, has its shoal environments dominated by skeletal packstone and grainstone microfacies (C5 and C12). The latter, represented by the Doi Long Formation, has its shoal environments dominated by peloidal algal microfacies (C4), and this microlithological difference can be employed as a stratigraphic criterion.

The Hong Hoi and Wang Chin Formations consist mainly of fine-grained turbidites. They can be divided into seven facies that are interpreted, based on facies associations and vertical facies sequences, to have been deposited as mud-dominated submarine fan sediments with detached sand bodies. Both formations consist mainly of middle-fan, outer-fan, overbank and basin plain sediments. The occurrence of rare slump and inner-fan sediments, and a lack of slope sediments support the interpretation of detached sand bodies. Sandstones commonly show Bouma structures with planar basal beds and no flute structures. There have been no fan lobe deposits. Their feeder systems may have been a multiple-point rather than single-point source, as suggested by lack of canyon deposits. These multiple-point sources may have initially been a slump and slide of shelf sediment piles that was triggered by slope failure. The cause of movement was possibly tectonic rather than eustatic changes in sea-level, since there is an apparent lack of Triassic glacial deposits. Coarse-grained sediments are recognized by the Mae Dum Sandstone and Mae Lu Sandstone Members. Since they may have been confined within channel areas, their shape may be wrapped by finer-grained sediments, as shown along Lampang- Denchai highway.

The Pha Daeng red beds are characteristically turbidites that formed mainly subaqueously as gravity flow sediments under shallow-water fan delta environments. The red beds were partly emergent, as indicated by mudcracks.

Provenance and tectonic implications

The sandstone composition of the Lampang Group consists mainly of volcanic derived fragments. Petrographical and chemical variations of sandstone turbidites indicate that the Hong Hoi and Pha Daeng Formations were derived mainly from active magmatic arc sources and accumulated in forearc basins above thin continental margins. The source rocks were changed during sedimentation of the Wang Chin Formation to a combination of recycled orogen and magmatic arc sources, possibly the result of uplifted accretionary prism and of continental collision. Sandstone petrography further indicates that the Triassic and older plutonic rocks are insignificant sources for sedimentation of the Lampang Group, as are high grade metamorphic rocks.

The sandstones of the Wang Chin Formation differ from sandstones of the Hong Hoi Formation in that they have a higher quartz content, more rounded quartz, and less microlitic texture in volcanic fragments. Both formations are lithic arkose to feldspathic litharenite in composition. High quartz content in the Wang Chin Formation may partly be due to subdued tectonism allowing intense weathering in the source area and producing mineralogically more mature sandstones. Change of the source rocks corresponds well with stratigraphies of the new Lampang Group proposed here, and is interpreted as a result of interaction between the Shan-Thai and westward subducting Indochina terranes. The collision was possibly mild and occurred during late Triassic Period.

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Appendix A-1 Original point-count data for the Hong Hoi Formation

Sample No.	Q		F		L				MC	H	U	Grain size	Q	F	L	Lt	Total
	Qm	Qp	P	K	Lv	Lm	Ls Lss	Lsc									
Tha Si Member																	
PL365	73	4	173	0	53	2	35	0	103	1	14	vf	77	173	90	94	458
PL476	68	8	140	1	101	2	17	2	92	1	7	c	76	141	120	128	439
LSM1	29	6	207	2	130	0	9	0	50	1	11	m	35	209	139	145	445
LSM2	90	5	207	60	59	2	0	0	43	2	5	c	95	267	61	66	473
LSM3	30	1	173	4	164	0	1	3	66	0	4	c	31	177	165	166	446
lower part of Mae Dum Sandstone Member																	
PL351	46	6	233	1	98	0	3	0	76	2	6	m	52	234	101	107	471
PL353	81	3	184	72	106	1	2	0	73	4	13	c	84	256	109	112	539
PL353	65	3	162	71	90	1	1	0	52	1	6	c	68	233	92	95	452
PL353-1	105	5	121	37	127	5	0	0	39	0	7	c	110	158	132	137	446
PL354	20	3	260	5	133	2	0	0	117	2	5	f	23	265	135	138	547
PL355	24	2	188	9	134	1	2	2	64	0	7	m-c	26	197	137	139	433
PL626	14	0	265	13	132	0	0	3	62	2	9	m-f	14	278	132	132	500
SSM1	39	2	213	10	132	0	0	0	43	1	0	m-c	41	223	132	134	440
upper part of Mae Dum Sandstone Member																	
PL367	41	6	250	2	228	0	3	0	164	9	27	c	47	252	231	237	730
PL368	17	1	340	18	218	0	3	0	118	3	2	m-f	18	358	221	222	720
PL370	28	4	222	1	163	0	0	14	288			m	32	223	163	167	720
PL371	24	0	206	2	151	0	2	3	56	2	5	m	24	208	153	153	451
PL372	31	1	157	0	129	0	14	5	66	4	9	c	32	157	143	144	416
SSM5	11	3	158	2	172	0	14	1	67	3	8	m-f	14	160	186	189	439
Huai Muang Member																	
PL357	34	0	227	0	75	0	1	29	37	0	8	m	34	227	76	76	411
PL374	35	5	161	1	133	1	0	24	94	4	2	m	40	162	134	139	460
PL377	54	4	108	0	66	6	1	39	126	0	3	c	58	108	73	77	407
USM1	40	0	212	0	104	1	1	17	41	3	10	c	40	212	106	106	429

Appendix A-2 Original point-count data for the Phra That and Pha Daeng Formations

Sample No.	Q		F		L				MC	H	U	Grain size	Q	F	L	Lt	Total
	Qm	Qp	P	K	Lv	Lm	Ls Lss	Lsc									
lower part of Pha Daeng Formation																	
PL360	78	9	159	0	110	0	14	2	29	4	18	f	87	159	126	135	405
PL361	170	0	161	8	43	0	4	8	50	6	15	c	170	169	55	55	450
PL387	47	0	113	0	70	0	9	117	67	2	9	m	47	113	196	196	425
PL388	28	1	109	0	80	0	17	181	211			m	29	109	278	279	627
PL390	31	1	191	1	101	1	2	25	60	1	2	m	32	192	129	130	414
PL507	16	1	130	0	234	1	0	0	100	2	0	m	17	130	235	236	484
PL656	50	9	192	2	101	0	2	14	113	2	6	f	59	194	117	126	485
PL657	144	6	178	2	140	2	8	12	84	3	26	c-m	150	180	162	168	579
PL701	94	16	172	0	166	0	4	0	38	0	32	c	110	172	170	186	490
upper part of Pha Daeng Formation																	
PL401	106	21	53	6	90	8	21	11	86	2	22	c	127	59	130	151	404
PL403	436	4	45	2	31	6	31	8	269	25	25	vf	440	47	76	80	857
PL404	168	2	116	6	28	4	4	0	122	4	4	vf	170	122	36	38	454
PL405	172	2	132	2	24	2	2	0	104	16	8	vf	174	134	28	30	456
Phra That Formation																	
PL602	305	8	8	0	33	1	0	0	52	1	15	m	313	8	34	42	408
PL603	284	16	9	0	51	2	1	0	66	0	12	m	300	9	54	70	429
PL604	308	11	3	0	36	1	1	0	42	1	22	m	319	3	38	49	403
PL605	302	3	3	0	47	1	2	0	45	0	5	m	305	3	50	53	403
PL606	337	3	1	0	38	0	2	0	48	0	6	m	340	1	40	43	429

Appendix A-3 Original point-count data for the Wang Chin Formation along the Lampang-Denchai highway

Sample No.	Q		F		L				MC	H	U	Grain size	Q	F	L	Lt	Total
	Qm	Qp	P	K	Lv	Lm	Ls: Lss	Lsc									
km 55.1 - 55.9																	
PL429	329	4	54	1	84	34	11	0	113	2	84	f	333	55	129	133	716
PL433	265	7	53	1	32	12	2	0	57	1	48	f	272	54	46	53	478
PL434	243	6	60	0	51	12	0	0	66	3	21	f	249	60	63	69	462
PL436	207	9	88	3	63	20	8	0	100	0	40	f	216	91	91	100	538
PL670	200	19	9	0	61	23	4	0	41	1	42	c	219	9	88	107	400
km 66.4 - 66.7																	
PL441	203	3	151	0	30	0	0	2	135	1	28	vf	206	151	30	33	553
PL442	57	9	78	0	135	1	9	49	87	1	23	c	66	78	145	154	449
PL444	209	4	159	2	104	4	6	1	131	0	15	m	213	161	114	118	635
PL452	196	6	169	0	173	3	11	6	172	1	19	m	202	169	187	193	756
PL674	156	3	157	0	55	2	6	2	184	1	4	f	159	157	63	66	570
km 68 - 68.3																	
PL464	325	30	195	1	157	10	12	14	181	1	15	m	355	196	179	209	941
PL594	155	0	100	0	71	3	6	1	93	0	5	f	155	100	80	80	434
PL597	114	18	141	1	39	4	1	8	77	1	13	f	132	142	44	62	417
PL597-1	149	2	108	0	73	0	1	0	82	2	5	f-m	151	108	74	76	422
PL598	155	2	103	1	70	1	0	0	92	0	8	m-f	157	104	71	73	432

Appendix B Catalogue of samples of the Triassic Lampang Group, housed at the Geology Department, University of Tasmania

UTGD	Field no.	Preparation	Lithology	Stratigraphy	Location
76113	PL 414	R	red mudstone	Phra That Fm	km 31+600 m, see Fig. 2.4E
76114	PL415	R	red sandstone	"	"
76115	PL17	PS	skeletal packstone/grainstone	Pha Kan Fm	see Fig. 2.4 A
76116	PL43	PS	oncolitic wackestone/packstone	"	"
76117	PL47	PS	oncolitic packstone	"	"
76118	PL53	R	oolitic grainstone	"	"
76119	PL60	PS	oncolitic packstone	"	"
76120	PL67	PS	oncolitic packstone	"	"
76121	PL85-1	PS	intraclastic grainstone	"	see Fig. 2.4 F
76122	PL100	PS	intraclastic grainstone	"	"
76123	PL219	R	packstone/wackestone	"	see Fig. 2.4 D
76124	PL230	PS	wackestone	"	"
76125	PL292	R	peloidal packstone	"	see Fig. 2.4 G
76126	PL300	R	oncolitic packstone	"	"
76127	C4	PS	oolitic packstone/wackestone	"	see Fig. 2.4 D
76128	C24	R	wackestone	"	see Fig. 2.4 G
76129	SC32	R	peloidal packstone	"	see Fig. 2.4 A
76130	SC45	R	wackestone	"	see Fig. 2.4 F
76131	PL353	R	conglomeratic sandstone	Hong Hoi Fm	Huai mae Dum, see Fig. 2.6 A
76132	PL354	PS	sandstone	"	"
76133	PL355	R	sandstone	"	"
76134	PL358	R	lime mudstone	"	Huai Muang, see Fig. 2.6 A
76135	PL367	R	sandstone	"	"
76136	PL368	R	sandstone	"	"
76137	PL369	R	sandstone	"	"
76138	PL372	R	conglomeratic sandstone	"	"
76139	PL374	R	sandstone	"	"

Appendix B (continued)

UTGD	Field no.	Preparation	Lithology	Stratigraphy	Location
76140	PL377	R	sandstone	Hong Hoi Fm	Huai Muang, see Fig. 2.6 A
76141	PL476	PS	sandstone	"	km 654+300 m, the Phaholyothin highway
76142	PL107	R	algal packstone	Doi Long Fm	Doi Long, see Fig. 2.7 C
76143	PL111	PS	algal wackestone/packstone	"	"
76144	PL117	PS	algal wackestone	"	"
76145	PL127	PS	oolitic packstone	"	Doi Nok, see Fig. 2.7 E
76146	PL134	R	algal packstone	"	"
76147	PL271	PS	algal packstone	"	Doi Huai Long, see Fig. 2.7 D
76148	C11	PS	skeletal packstone	"	"
76149	C12	PS	algal packstone	"	"
76150	C20	PS	algal packstone	"	Ban Pang La, see Fig. 2.7 A
76151	C39	R	wackestone	"	Doi Pha Bong, see Fig. 2.7 B
76152	PL360	R	red sandstone	Pha Daeng Fm	Doi Pha Daeng, see Fig. 2.8 A
76153	PL387	PS	limestone conglomerate	"	"
76154	PL388	R	red sandstone	"	"
76155	PL390	R	sandstone	"	"
76156	PL393	R	red sandstone	"	"
76157	PL399	R	red sandstone	"	"
76158	PL401	R	red sandstone	"	"
76159	PL402	R	red sandstone	"	"
76160	PL403	R	red sandstone	"	"
76161	PL404	R	sandstone	"	"
76162	PL405	PS	sandstone	"	"
76163	PL507	R	sandstone	"	see Fig. 2.10 A
76164	PL515	PS	red siltstone	"	see Fig. 2.10 D
76165	PL160	R	intraclastic grainstone/wkst	Kang PLa Fm	see Fig. 2.10 A

Appendix B (continued)

UTGD	Field no.	Preparation	Lithology	Stratigraphy	Location
76166	PL167	R	mudstone	Wang Chin Fm	see Fig. 2.10 C
76167	PL187	PS	siltstone	"	"
76168	PL419	R	sandstone	"	see Fig. 2.12 B
76169	PL423	R	mudstone with parallel burrows	"	"
76170	PL425	R	mudstone with ?chondrite	"	"
76171	PL433	R	sandstone	"	"
76172	PL436	R	sandstone	"	"
76173	PL437	PS	mudstone	"	"
76174	PL439-1	PS	mudstone	"	"
76175	PL440	PS	mudstone	"	see Fig. 2.12 C
76176	PL443	R	sandstone	"	"
76177	PL444	R	sandstone	"	"
76178	PL445	PS	sandstone	"	"
76179	PL450	PS	mudstone	"	"
76180	PL452	R	sandstone	"	"
76181	PL464	R	sandstone	"	see Fig. 2.12 D
76182	SC10	PS	allodapic limestone	"	see Fig. 2.10 D
76183	C42	R	lime mudstone	"	see Fig. 2.12 C